State of California
The Resources Agency
Department of Water Resources

DRAFT FINAL REPORT
SP-G1

EFFECTS OF PROJECT OPERATIONS ON GEOMORPHIC PROCESSES UPSTREAM OF OROVILLE DAM

Oroville Facilities Relicensing
FERC Project No. 2100

APRIL 2004

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REPORT SUMMARY

The two primary tasks of SP-G1 are to assess channel resources (both above Lake Oroville and within the Fluctuation Zone) and determine the total sediment in storage by re-surveying the existing reservoir cross-sections and accessing other geomorphological conditions around the reservoir such as slope stability and bank erosion.

Professional biological assessment of habitat is beyond the scope of this study plan. However, based on the geomorphological assessment and habitat typing of the West Branch and the Middle Fork tributaries above the full pool level (i.e., 900 feet) of Lake Oroville, impacts due to project operations were not observed. Fluctuating water levels discourage substantial delta and sediment deposits above the 900 foot level.

At the time of the field investigation for this study, upper portions of the fluctuation zone were exposed to fluvial (as opposed to lentic) conditions. Based on the geomorphological assessment and habitat typing of the four main tributaries within the fluctuation zone, the following preliminary conclusions are presented:

- The West Branch has in-stream gravel strata generally considered suitable for salmon spawning habitat in the upper portion of the Fluctuation Zone but silt accumulation on the downstream portions causes a degradation in spawning gravel quality
- Salmon spawning habitat in the North Fork is affected because of daily fluctuating flows from upstream hydroelectric facilities.
- The Middle Fork has abundant gravel sources from remnant sediment wedge lag deposits.
- The South Fork is gravel-starved above Sucker Run Creek and is subject to flow variations due to Ponderosa Dam. Spawning gravel quality improves downstream of Sucker Run Creek but gradually becomes sandier from remnant sediment wedge deposits.

Future flooding events (similar to 1997) will cause temporary episodic impacts to salmonid habitat in the upper portions of the Fluctuation Zone (from 800 ft to 900 ft) if floods occur at full pool level.

The cross-section and thalweg bathymetry surveys revealed that substantial amounts of sediment occur in the middle upper arms of the lake ranging from about 720 feet in elevation to about 550 feet. Minor amounts of sediment were identified above the 720 foot level at the time of this investigation. Sediment accumulation rates in the cross section thalwegs downstream from the sediment wedges range from about 0.5 feet to 2.25 feet per year, averaging about 1.25 feet per year. It is uncertain if this sedimentation rate will continue; however, the rate is likely to decrease as sedimentation continues and the thalweg width increases.

Based on calculations derived from the cross-section and bathymetry surveys, the total volume of sediment in storage is about 28,300 acre-feet. Of this amount, about 11,400 acre-feet was estimated to be derived from shoreline bank erosion, and the remaining 16,900 acre-feet was identified as incoming sediment from the upstream watersheds. Based on a 36 year time period since the initial filling of Lake Oroville, annual sediment yield is about 470 acre-feet. If this rate of sediment field were to remain constant, sediment would completely fill the reservoir in about 7,400 years

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOS
(Photos placed in separate section)

LIST OF PLATES

1.0 INTRODUCTION

1.1 BACKGROUND INFORMATION

The Environmental Working Group (EWG) identified a number of issues to be addressed by this study plan. Major issues included project effects on reservoir sedimentation, shoreline erosion and mass wasting, tributary channel geomorphology, and sediment transport in the Feather River in and above Lake Oroville. Secondary effects of the geomorphic changes could include effects on fisheries, fish migration barriers and shoreline vegetation

1.1.2 Study Area

1.1.2.1 Description

The study area includes Lake Oroville and its adjacent shoreline, and incoming branches of the Feather River up to their first fish passage barrier (Figure 1.1-1).

1.1.2.1.1 Tributaries Tributary study areas included all branches of the Feather River upstream from the lake to their first fish barrier (natural or manmade) (Table 1.1-1). An additional ten smaller tributaries (2^{nd} order or larger) that drain directly into the reservoir were also initially included (Table 1.1-2). No notable project effects were determined for these additional tributaries and they will not be discussed further. Stream profiles for the incoming branches of the Feather River are shown in Plates 1.1-1 through 1.1-4. In this report, the West Branch of the North Fork of the Feather River will be referred to as the West Branch. The North, Middle and South Forks of the Feather River will be referred to as the North Fork, Middle Fork, and South Fork, respectively.

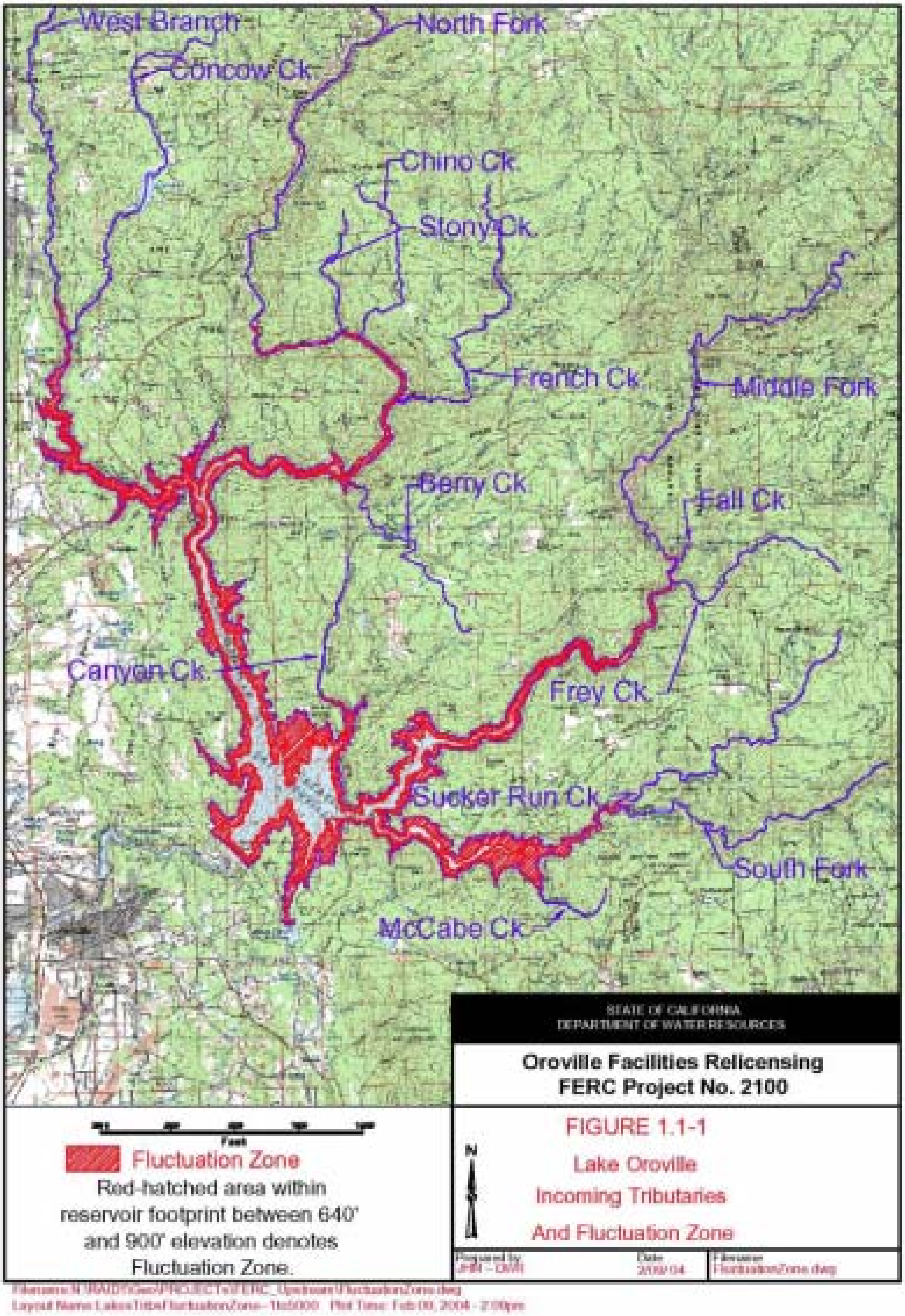


Figure 1.1-1. SP-G1 Study Area

Table 1.1-1. Lake Oroville Main Tributaries.

Name	Fish Barrier Name	Barrier Elevation	Tributary Length (ft)
West Branch Feather River	Miocene Dam	1,550’	30,700
North Fork Feather River	Big Bend Dam	900’	N/A
Middle Fork Feather River	Curtain Falls	1,200’	30,600
South Fork Feather River	Ponderosa Dam	900’	N/A

Table 1.1-2. Lake Oroville Smaller Tributaries.

Name	Location in Reference to Main Tributary	Tributary Length (ft)
Concow Creek	West Branch	18,800
Stony Creek	North Fork	5,700
Chino Creek	North Fork	8,400
French Creek	North Fork	14,700
Berry Creek	North Fork	9,800
Fall River (to Feather Falls)	Middle Fork	900
Frey Creek	Middle Fork	9,100
Canyon Creek	Middle Fork	40,000
Sucker Run Creek	South Fork	52,400
McCabe Creek	South Fork	5,700

1.1.2.1.2 Fluctuation Zone The area within the maximum pool level of Lake Oroville was subdivided into two zones based mainly on Project operations. The area of the reservoir above the 640 foot elevation to the maximum pool elevation of 900 feet is defined as the Fluctuation Zone. This zone is repeatedly inundated and exposed as lake levels rise and fall.

1.1.2.1.3 Reservoir Storage Zone The Reservoir Storage Zone is defined as that portion of Lake Oroville that is below the 640 foot elevation. The Reservoir Storage Zone has been inundated ever since the initial filling of Lake Oroville in 1967. The lowest lake levels that have been attained to date were 645.11 feet on September 7, 1977 and 651.48 feet on January 30, 1991.

1.2 DESCRIPTION OF FACILITIES

The Oroville Facilities were developed as part of the State Water Project (SWP), a water storage and delivery system of reservoirs, aqueducts, power plants, and pumping plants. The main purpose of the SWP is to store and distribute water to supplement the needs of urban and agricultural water users in northern California, the San Francisco Bay area, the San Joaquin Valley, and southern California. The Oroville Facilities are also operated for flood management, power generation, to improve water quality in the Delta, provide recreation, and enhance fish and wildlife.

FERC Project No. 2100 encompasses 41,100 acres and includes Oroville Dam and Reservoir, three power plants (Hyatt Pumping-Generating Plant, Thermalito Diversion Dam Power Plant, and Thermalito Pumping-Generating Plant), Thermalito Diversion Dam, the Feather River Fish Hatchery and Fish Barrier Dam, Thermalito Power Canal, Oroville Wildlife Area (OWA), Thermalito Forebay and Forebay Dam, Thermalito Afterbay and Afterbay Dam, and transmission lines, as well as a number of recreational facilities. An overview of these facilities is provided on Figure 1.2-1. The Oroville Dam, along with two small saddle dams, impounds Lake Oroville, a 3.5-million-acre-feet (maf) capacity storage reservoir with a surface area of 15,810 acres at its normal maximum operating level.

The hydroelectric facilities have a combined licensed generating capacity of approximately 762 megawatts (MW). The Hyatt Pumping-Generating Plant is the largest of the three power plants with a capacity of 645 MW. Water from the six-unit underground power plant (three conventional generating and three pumping-generating units) is discharged through two tunnels into the Feather River just downstream of Oroville Dam. The plant has a generating and pumping flow capacity of 16,950 cfs and 5,610 cfs, respectively. Other generation facilities include the 3-MW Thermalito Diversion Dam Power Plant and the 114-MW Thermalito Pumping-Generating Plant.

Thermalito Diversion Dam, four miles downstream of the Oroville Dam, creates a tail water pool for the Hyatt Pumping-Generating Plant and is used to divert water to the Thermalito Power Canal. The Thermalito Diversion Dam Power Plant is a 3-MW power plant located on the left abutment of the Diversion Dam. The power plant releases a maximum of 615 cubic feet per second (cfs) of water into the river.

The Power Canal is a 10,000-foot-long channel designed to convey generating flows of 16,900 cfs to the Thermalito Forebay and pump-back flows to the Hyatt Pumping-Generating Plant. The Thermalito Forebay is an off-stream regulating reservoir for the 114-MW Thermalito Pumping-Generating Plant. The Thermalito Pumping-Generating Plant is designed to operate in tandem with the Hyatt Pumping-Generating Plant and has generating and pump-back flow capacities of 17,400 cfs and 9,120 cfs, respectively.

When in generating mode, the Thermalito Pumping-Generating Plant discharges into the Thermalito Afterbay, which is contained by a 42,000-foot-long earth-fill dam. The Afterbay is used to release water into the Feather River downstream of the Oroville Facilities, helps regulate the power system, provides storage for pump-back operations, and provides recreational opportunities. Several local irrigation districts receive water from the Afterbay.

The Feather River Fish Barrier Dam is downstream of the Thermalito Diversion Dam and immediately upstream of the Feather River Fish Hatchery. The flow over the dam maintains fish habitat in the low-flow channel of the Feather River between the dam and the Afterbay outlet, and provides attraction flow for the hatchery. The hatchery was intended to compensate for spawning grounds lost to returning salmon and steelhead trout from the construction of Oroville Dam. The hatchery can accommodate 15,000 to 20,000 adult fish annually.

The Oroville Facilities support a wide variety of recreational opportunities. They include: boating (several types), fishing (several types), fully developed and primitive camping (including boat-in and floating sites), picnicking, swimming, horseback riding, hiking, off-road bicycle riding, wildlife watching, hunting, and visitor information sites with cultural and informational displays about the developed facilities and the natural environment. There are major recreation facilities at Loafer Creek, Bidwell Canyon, the Spillway, North and South Thermalito Forebay, and Lime Saddle. Lake Oroville has two full-service marinas, five car-top boat launch ramps, ten floating campsites, and seven dispersed floating toilets. There are also recreation facilities at the Visitor Center and the OWA.

The OWA comprises approximately 11,000-acres west of Oroville that is managed for wildlife habitat and recreational activities. It includes the Thermalito Afterbay and surrounding lands (approximately 6,000 acres) along with 5,000 acres adjoining the Feather River. The 5,000 acre area straddles 12 miles of the Feather River, which includes willow and cottonwood lined ponds, islands, and channels. Recreation areas include dispersed recreation (hunting, fishing, and bird watching), plus recreation at developed sites, including Monument Hill day use area, model airplane grounds, three boat launches on the Afterbay and two on the river, and two primitive camping areas. California Department of Fish and Game's (DFG) habitat enhancement program includes a wood duck nest-box program and dry land farming for nesting cover and improved wildlife forage. Limited gravel extraction also occurs in a number of locations.

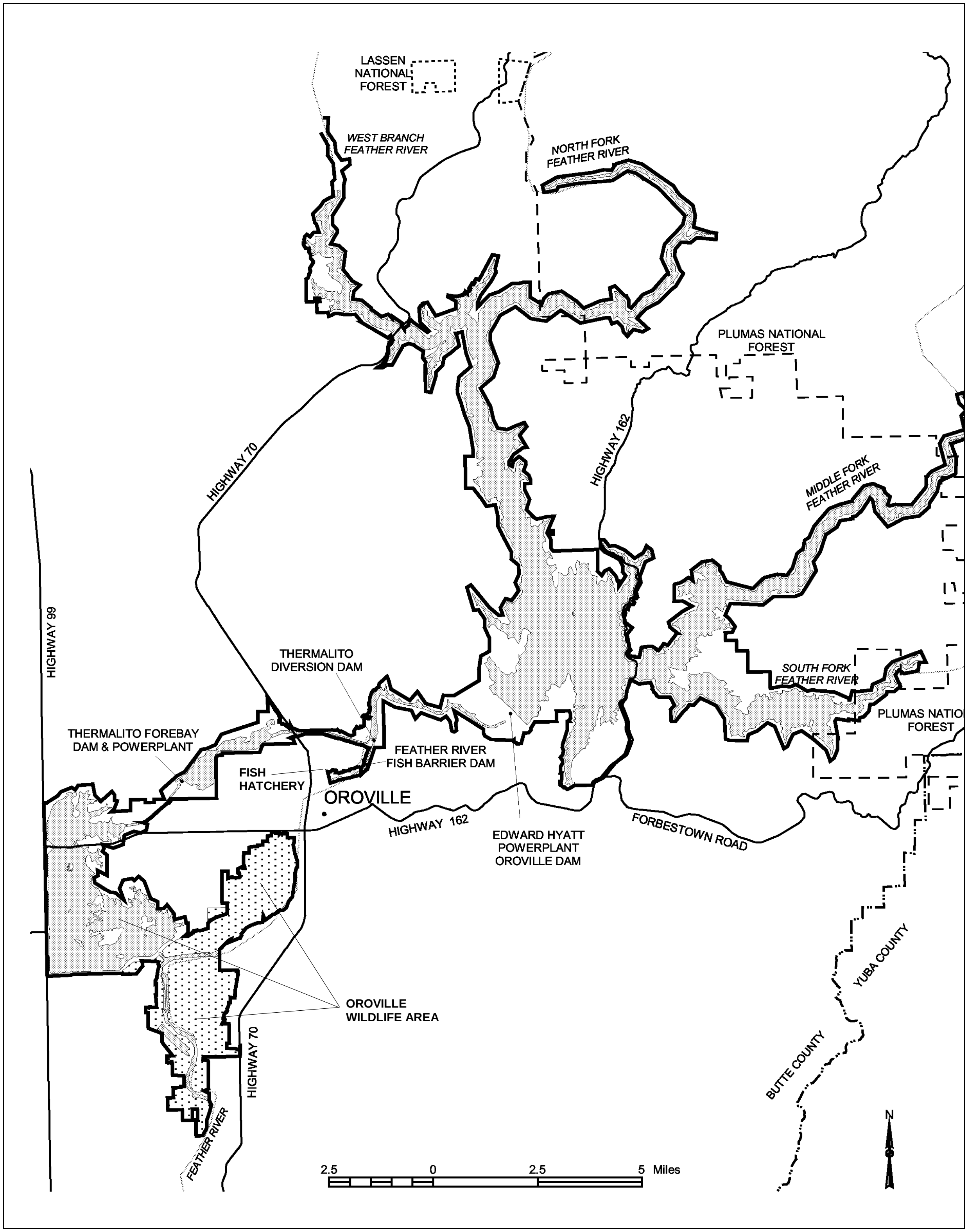


Figure 1.2-1. Oroville Facilities FERC Project Boundary

1.3 CURRENT OPERATIONAL CONSTRAINTS

Operation of the Oroville Facilities varies seasonally, weekly and hourly, depending on hydrology and the objectives DWR is trying to meet. Typically, releases to the Feather River are managed to conserve water while meeting a variety of water delivery requirements, including flow, temperature, fisheries, recreation, diversion and water quality. Lake Oroville stores winter and spring runoff for release to the Feather River as necessary for project purposes. Meeting the water supply objectives of the SWP has always been the primary consideration for determining Oroville Facilities operation (within the regulatory constraints specified for flood control, in-stream fisheries, and downstream uses). Power production is scheduled within the boundaries specified by the water operations criteria noted above. Annual operations planning is conducted for multi-year carry over. The current methodology is to retain half of the Lake Oroville storage above a specific level for subsequent years. Currently, that level has been established at 1,000,000 acre-feet (af); however, this does not limit draw down of the reservoir below that level. If hydrology is drier than expected, or requirements greater than expected, additional water would be released from Lake Oroville. The operations plan is updated regularly to reflect changes in hydrology and downstream operations. Typically, Lake Oroville is filled to its maximum annual level of up to 900 feet above mean sea level (msl) in June and then can be lowered as necessary to meet downstream requirements, to its minimum level in December or January. During drier years, the lake may be drawn down more and may not fill to the desired levels the following spring. Project operations are directly constrained by downstream operational constraints and flood management criteria as described below.

1.3.1 Downstream Operation

An August 1983 agreement between DWR and DFG entitled, “Agreement Concerning the Operation of the Oroville Division of the State Water Project for Management of Fish & Wildlife,” sets criteria and objectives for flow and temperatures in the low flow channel and the reach of the Feather River between Thermalito Afterbay and Verona. This agreement: (1) establishes minimum flows between Thermalito Afterbay Outlet and Verona which vary by water year type; (2) requires flow changes under 2,500 cfs to be reduced by no more than 200 cfs during any 24-hour period, except for flood management, failures, etc.; (3) requires flow stability during the peak of the fall-run Chinook spawning season; and (4) sets an objective of suitable temperature conditions during the fall months for salmon and during the later spring/summer for shad and striped bass.

1.3.1.1 Instream Flow Requirements

The Oroville Facilities are operated to meet minimum flows in the Lower Feather River as established by the 1983 agreement (see above). The agreement specifies that Oroville Facilities release a minimum of 600 cfs into the Feather River from the

Thermalito Diversion Dam for fisheries purposes. This is the total volume of flows from the diversion dam outlet, diversion dam power plant, and the Feather River Fish Hatchery pipeline.

Generally, the instream flow requirements below Thermalito Afterbay are 1,700 cfs from October through March, and 1,000 cfs from April through September. However, if runoff for the previous April through July period is less than 1,942,000 af (i.e., the 1911-1960 mean unimpaired runoff near Oroville), the minimum flow can be reduced to 1,200 cfs from October to February, and 1,000 cfs for March. A maximum flow of 2,500 cfs is maintained from October 15 through November 30 to prevent spawning in overbank areas that might become de-watered.

1.3.1.2 Temperature Requirements

The Diversion Pool provides the water supply for the Feather River Fish Hatchery. The hatchery objectives are 52°F for September, 51°F for October and November, 55°F for December through March, 51°F for April through May 15, 55°F for last half of May, 56°F for June 1-15, 60°F for June 16 through August 15, and 58°F for August 16-31. A temperature range of plus or minus 4°F is allowed for objectives, April through November.

There are several temperature objectives for the Feather River downstream of the Afterbay Outlet. During the fall months, after September 15, the temperatures must be suitable for fall-run Chinook. From May through August, they must be suitable for shad, striped bass, and other warmwater fish.

The National Marine Fisheries Service has also established an explicit criterion for steelhead trout and spring-run Chinook salmon. Memorialized in a biological opinion on the effects of the Central Valley Project and SWP on Central Valley spring-run Chinook and steelhead as a reasonable and prudent measure; DWR is required to control water temperature at Feather River mile 61.6 (Robinson's Riffle in the low-flow channel) from June 1 through September 30. This measure requires water temperatures less than or equal to 65°F on a daily average. The requirement is not intended to preclude pump-back operations at the Oroville Facilities needed to assist the State of California with supplying energy during periods when the California ISO anticipates a Stage 2 or higher alert.

The hatchery and river water temperature objectives sometimes conflict with temperatures desired by agricultural diverters. Under existing agreements, DWR provides water for the Feather River Service Area (FRSA) contractors. The contractors claim a need for warmer water during spring and summer for rice germination and growth (i.e., 65°F from approximately April through mid May, and 59°F during the remainder of the growing season). There is no obligation for DWR to meet the rice water temperature goals. However, to the extent practical, DWR does use its operational flexibility to accommodate the FRSA contractor's temperature goals.

1.3.1.3 Water Diversions

Monthly irrigation diversions of up to 190,000 af (July 2002) are made from the Thermalito Complex during the May through August irrigation season. Total annual entitlement of the Butte and Sutter County agricultural users is approximately 1 maf. After meeting these local demands, flows into the lower Feather River continue into the Sacramento River and into the Sacramento-San Joaquin Delta. In the northwestern portion of the Delta, water is pumped into the North Bay Aqueduct. In the south Delta, water is diverted into Clifton Court Forebay where the water is stored until it is pumped into the California Aqueduct.

1.3.1.4 Water Quality

Flows through the Delta are maintained to meet Bay-Delta water quality standards arising from DWR's water rights permits. These standards are designed to meet several water quality objectives such as salinity, Delta outflow, river flows, and export limits. The purpose of these objectives is to attain the highest water quality, which is reasonable, considering all demands being made on the Bay-Delta waters. In particular, they protect a wide range of fish and wildlife including Chinook salmon, Delta smelt, striped bass, and the habitat of estuarine-dependent species.

1.3.2 Flood Management

The Oroville Facilities are an integral component of the flood management system for the Sacramento Valley. During the wintertime, the Oroville Facilities are operated under flood control requirements specified by the U.S. Army Corps of Engineers (USACE). Under these requirements, Lake Oroville is operated to maintain up to 750,000 af of storage space to allow for the capture of significant inflows. Flood control releases are based on the release schedule in the flood control diagram or the emergency spillway release diagram prepared by the USACE, whichever requires the greater release. Decisions regarding such releases are made in consultation with the USACE.

The flood control requirements are designed for multiple use of reservoir space. During times when flood management space is not required to accomplish flood management objectives, the reservoir space can be used for storing water. From October through March, the maximum allowable storage limit (point at which specific flood release would have to be made) varies from about 2.8 to 3.2 maf to ensure adequate space in Lake Oroville to handle flood flows. The actual encroachment demarcation is based on a wetness index, computed from accumulated basin precipitation. This allows higher levels in the reservoir when the prevailing hydrology is dry while maintaining adequate flood protection. When the wetness index is high in the basin (i.e., wetness in the watershed above Lake Oroville), the flood management space required is at its greatest amount to provide the necessary flood protection. From April through June, the maximum allowable storage limit is increased as the flooding potential decreases, which allows capture of the higher spring flows for use later in the year. During September, the maximum allowable storage decreases again to prepare for the next flood season. During flood events, actual storage may encroach into the flood reservation zone to prevent or minimize downstream flooding along the Feather River.

2.0 NEED FOR STUDY

Participants in the relicensing process identified several concerns related to the effects of Oroville operations on branches of the Feather River above the lake. This study addresses those concerns by evaluating topics including effects of lake level fluctuations on tributary sediment transport, sediment inputs to the lake and shoreline erosion and mass wasting. Information obtained from this study will be used to help determine project effects on other resources such as fisheries, wildlife and water quality. The data provided by this study may also be used to direct changes in management to offset adverse environmental effects.

3.0 STUDY OBJECTIVES

This study directly or indirectly addresses the following specific issues identified by the Environmental Working Group, or raised in written comments and environmental scoping documents:

- The effects of accumulated sediment on the capacity of Lake Oroville, including the characterization of sediment quantity and quality.
- The effects of project operations on sediment movement and deposition and channel morphology in upstream branches of the Feather River.
- The effects of project operations on fish habitat in upstream branches of the Feather River.
- The effects of project operations on shoreline erosion and mass wasting within the fluctuation zone of Lake Oroville.

The work plan for SP-G1 identified five individual tasks:

1) Obtain, Review and Synthesize Existing Resource Data
2) Map Instream Habitats in the Branches of the Feather River above Oroville Dam
3) Re-Survey Reservoir Cross-Sections and Determine Sediment in Storage
4) Cross-Section Monitoring
5) Determine Changes in Geomorphic and Hydraulic Parameters of the Feather River, based on findings in Tasks 1 through 4

This report addresses each of the first three tasks separately and presents the methodologies used, study results, and conclusions. Because tributary flows of geomorphological significance did not occur during the time frame of this study, Task 4 was not performed; cross-section monitoring of cross-sections surveyed above Lake Oroville are expected to be monitored during the FERC relicensing process. Conclusions contained in Tasks 1 through 3 address Task 5.

4.0 TASK 1—REVIEW OF EXISTING RESOURCE DATA

4.1 CONSULTATION WITH SOURCES OUTSIDE OF DWR

Consultations with county, state and federal agencies were conducted during the preparation of this report. In addition, representatives from Pacific, Gas & Electric Company, South Fork Water & Power Company, and the Feather River Coordinated Resource Management Group were contacted. The purpose of these consultations was to determine what data might be available from these entities for conducting this study. Data obtained from these sources included current status of sedimentation studies in upstream reservoirs and erosion studies and projects being conducted in the upstream watershed.

4.2 INITIAL SHORELINE SURVEY

A reconnaissance survey of the lake perimeter was conducted early in 2002 when lake level elevations ranged from 740 to 840 feet. Upper reaches of the main tributaries were surveyed to the uppermost extent of the lake arms in spring 2003 when the reservoir was at or near full pool level. Lake Oroville abuts against Big Bend Dam on the North Fork and Ponderosa Dam on the South Fork; the West Branch and Middle Fork flow unobstructed directly into the reservoir (Photos 4.2-1 through 4.2-4). Miocene Dam on the West Branch and Curtain Falls on the Middle Fork are traditionally recognized fish barriers for upstream migratory fish (Photos 4.2-5 and 4.2-6). A primary concern raised by participants of the EWG was the possible upstream channel changes (such as increased sediment aggradation, or fish migration barriers) in response to fluctuating lake levels in Lake Oroville. Project operations do not maintain the reservoir level at full pool level over long periods of time; generally the reservoir is at or near full pool level in late spring, then gradually lowered through the summer as project water delivery demands are met. As a result, no significant sediment deposits, deltas or bars were observed at or above the full pool level. Because of these initial observations, work that was planned for investigating assumed sediment features upstream of Lake Oroville was redirected.

4.3 REVIEW OF PREVIOUS WORK

4.3.1 Mapping

Standard 7½" topographic maps were utilized for the study base map. Archival research at DWR's Photogrammetry Section revealed that detailed mapping of the Lake Oroville footprint area and adjacent side slopes had been developed based on aerial photography flown in September 1965. Generally, these maps were drawn on a plastic mylar base at a scale of 1:4800 (i.e., 1 inch = 400 feet) and a contour interval of 20 feet. Northern District staff scanned the mylar maps into computer graphic TIF (Tagged

Image Format) files. Staff then geo-referenced the TIF files so that they could be properly inserted into the base map file and incorporated into the Oroville Facilities Relicensing GIS database.

DWR published a detailed geologic map of the Lake Oroville area as part of the August 1, 1975 Oroville Earthquake Investigations (DWR, 1979). This map was digitized and geo-referenced for incorporation into a base geology map (Appendix A, Plates 1-8). DWR also prepared a preliminary geology and landslide map of Lake Oroville in 1963 (DWR, 1963) that was reviewed and incorporated into the base geology map. Mapped geology of portions that were unmapped in neither the 1978 map nor the 1963 map (primarily upper sections of the Middle and South Fork) were obtained from United States Geological Survey (USGS) and California Geological Survey (CGS) geologic map sheets.

4.3.2 Feather River Basin Physiography

DWR published a draft watershed report for the North Fork and Middle Fork Feather River in 1994 (DWR, 1994). During the course of the present study, this report was updated and expanded to include existing information on the West Branch and South Fork. Study Plan Report G-2 Task 1.2 contains more detailed information on the Feather River basin physiography.

The watershed above Lake Oroville drains an area of 3,611 square miles The North Fork and Middle Fork watersheds comprise 3,222 square miles of this area, including portions of the foothill and mountain regions of the northern Sierra Nevada and southern Cascade Range. The South Fork and the West Branch watersheds contain the additional 389 square miles.

The North Fork basin is roughly triangular, oriented in the east-west direction, with a point of the triangle meeting the confluence of the Middle Fork in Lake Oroville (Figure 4.3-1). The basin's maximum length and width are 65 and 75 miles respectively.

The Middle Fork basin is roughly crescent- shaped. It is elongated along an east-west axis with its maximum length and width approximately 75 and 35 miles respectively.

The South Fork has a drainage area of about 247 square miles. It skirts the southwest portion of the Feather River Watershed and mostly drains the lower foothills of the Sierra Nevada. The West Branch is also small, draining about 142 square miles east and northeast of Paradise.

In the lower two-thirds of the Feather River watershed both the Middle and North forks flow in deeply incised canyons with little or no floodplain. In the upper one-third of the watershed, streams historically flowed in shallow meandering channels with broad floodplains covered with riparian vegetation. Floodwaters would quickly overtop the banks and

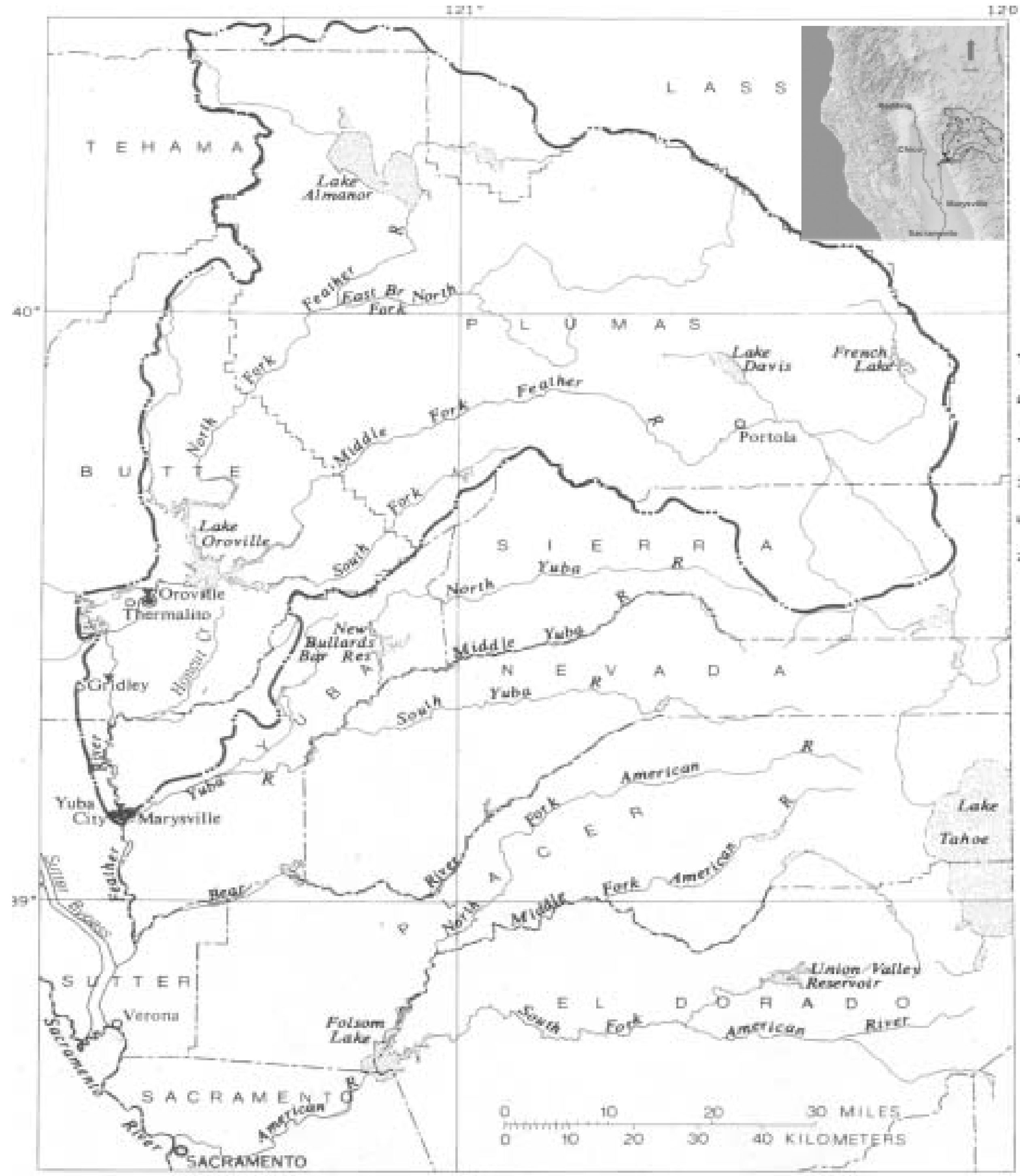


Figure 4.3-1. Feather River Watershed, Lower River, and Hydrography

deposit sediment on the valley floor. Under present conditions, land use changes have caused many of the headwater streams to lose their meander patterns and form into sharp V-shaped channels devoid of vegetation. The tall banks along these channels are easily eroded.

4.3.3 Sediment Sources in the Feather River Watershed

The upper Feather River watershed is producing high sediment yields due to accelerated erosion. A U.S. Soil Conservation Service report, *East Branch North Fork Feather River Erosion Inventory Report* (USSCS, 1989), estimated that ninety percent of the erosion in its 1,209 square mile study area was accelerated erosion. Accelerated erosion is a soil loss rate greater than natural geologic conditions and is caused by such human activities as road building, timber harvesting, overgrazing livestock, and agriculture. High sediment yield can reduce reservoir capacity, degrade water quality, and harm fish and wildlife. High sediment yields have significantly impaired storage capacity and hydroelectric operations in several reservoirs upstream of Lake Oroville on the North Fork Feather River.

A large amount of sediment is captured by reservoirs upstream of Lake Oroville. Lake Oroville captures nearly all of the remaining sediment. This in turn results in a sediment-starved river system below the dam. It is estimated that the trap efficiency of the reservoir is above 97 percent. A portion of silt and clay is discharged to the Feather River below the dam, but no pebbles, gravel, or cobbles.

Past watershed instability, erosion, and sedimentation investigations have focused largely on tributaries of the North Fork with little attention to the Middle Fork watershed. This focus on the North Fork and its tributaries reflects concern over excessive sedimentation and increased maintenance effectively reducing the operating efficiency and life span of reservoirs and power plants. In addition, landslides cause increased sedimentation and downstream cumulative effects. Erosion and downcutting of streams lowers groundwater levels and dewaters meadows. Reduced stream flow in the late summer and fall from dewatered meadows reduces hydropower generation capability. The dewatering of meadows has also resulted in their transformation from perennial grasses to dryland vegetation such as sagebrush

4.3.4 Classification of Upstream Reaches

No existing information was found regarding stream classifications and habitat typing in the major tributaries immediately upstream from Lake Oroville.

4.3.5 Studies of Lake Sedimentation

4.3.5.1 1971 Cross-Section Study

DWR initiated a study of reservoir cross-sections in 1971, four years after the initial filling of the reservoir (DWR, 1971). Twenty-four cross-section locations were selected and monumented. The cross-section profiles were measured while the reservoir was at near-full pool level (900') using a current state-of-the-art Raytheon fathometer. The 1971 study concluded that very little siltation of the reservoir had occurred since the initial filling of the reservoir started in November 1967. An exception was the uppermost cross-section in the Middle Fork (MF-8), where approximately 20 feet of sediment was detected. The study recommended that future siltation studies be made at intervals of 10 years or more, and that the two uppermost cross-sections on both the North Fork (NF-8 and NF-9) and the Middle Fork (MF-7 and MF-8) should be used as an index of the amount of siltation that had occurred since the previous survey.

4.3.5.2 1993-94 Cross-Section Study

Seventeen of the original 24 cross-sections were re-surveyed in 1993 and 1994 to determine sedimentation rates in the North Fork and Middle Fork of the reservoir (DWR, 1994). The four uppermost cross-sections in both the North Fork and the Middle Fork (NF-9, NF-8, NF-7, NF-6, MF-8, MF-7, MF-6, and MF-5) were surveyed in 1993 and the remaining nine sections (WB-1, NF-5, NF-4, NF-3, NF-2, MF-4, MF-3, MF-2, and MF-1) were surveyed in 1994. Cross-sections were not measured in the South Fork because Ponderosa Reservoir is directly above Lake Oroville and captures much of the sediment. Only the lowermost cross-section (WB-1) was measured in the West Branch. On eight of the cross-sections, at least one of the end point monuments was missing (most likely due to bank erosion effects) and was re-established. Cross-section bathymetry was measured using an electronic depth-finder and a transducer with a 4-degree cone; cross-section profiles above the water elevation were measured using a theodolite and electronic distance meter.

The 1994 report concluded that an average depth of about 15 feet of sedimentation had occurred in the lake for a total sediment volume of about 18,000 acre-feet. The report also stated that, based on field observations, an average of about one foot of erosion had occurred along most of the reservoir shoreline, for an estimated total sediment yield of 6,500 acre-feet due to bank erosion.

Specifically, the 1994 report indicated that all cross-sections in the North Fork and Middle Fork showed deposition except for the two uppermost cross-sections in both arms (i.e., NF-8, NF-9, MF-7, and MF-9). The authors of the report assumed that deposition had occurred in the four uppermost cross-sections since the 1971 survey, but that low lake levels during drought periods (1976-1977, and 1987-1992) had exposed the sediment to streamflow and that the sediment now resided further downstream.

4.3.6 Woody Debris Input to Reservoir

Floating woody debris in Lake Oroville is most prevalent in the late spring when the reservoir reaches its yearly maximum elevation. If the maximum lake elevation for a given year exceeds the lake elevation for several previous years (i.e., a wet year following several dry years), more woody debris enters the lake as the reservoir covers areas that have not been inundated for several years. Woody debris is carried into Lake Oroville from the tributary streams during major storm events. The storms of 1997 resulted in such large quantities of woody debris in the lake that commercial timber salvage was allowed.

The Departments Oroville Field Division manages woody debris on Lake Oroville. Typically, floating debris is gathered behind log booms in the upper arms of the main tributaries and in the main basin. Periodically, the collected debris is barged to the McCabe Creek area on the South Fork where it is placed behind a log boom and allowed to settle along the shoreline as the reservoir level recedes. The areal extent of the debris in summer 2003 was approximately five acres and one to two feet thick (Photo 4.3-1). The total estimated volume in 2003 was approximately 1,100 cubic yards. Most pieces were less than 10 feet long and one foot in diameter. Oroville Field Division staff considered 2003 to be a lighter than normal year in volume of woody debris accumulated (pers. comm.., O'Briant 2003). In late fall, the debris is gathered into piles (Photos 4.3-2 and 4.3-3) and burned, or chipped for fuel in a cogeneration facility. Oroville Field Division staff believes that most of the wood debris is derived from lake shore slopes, with a minor amount derived from upstream tributaries. It is probable that a much larger portion of the woody debris actually does originate from tributaries above the reservoir, but that much of the debris is stranded along the lower lake areas by the time crews begin collecting the debris, thus suggesting it is derived from lake shore slopes rather than upstream tributaries.

4.1.7 Conclusions

During development of the SP-G1 study plan, it was assumed that project operations would have a significant effect on stream geomorphology upstream of Lake Oroville (i.e., above the full pool level) such as sediment deposition and the formations of deltas. However, because project operations include an annual lake level fluctuation of 50 to 250 feet, sediment deposition does not occur above Lake Oroville. The initial shoreline survey, performed while reservoir levels were between 690 and 840 feet, did indicate that substantial sediment deposition does occur within the Fluctuation Zone. Consultations with participants of the EWG recommended that study tasks originally directed towards features upstream of Lake Oroville be redirected toward features within the Fluctuation Zone. Studies upstream of Lake Oroville were therefore limited to mapping channel resources in support of the SP-F3 study plan.

5.0 TASK 2—MAP THE CHANNEL RESOURCES IN THE TRIBUTARIES ABOVE OROVILLE DAM

Channel resources investigations were separated into two components based on their location in reference to the full pool elevation (900 feet) of Lake Oroville. The channel resources above the 900 foot elevation are never inundated by the lake and are always subject to fluvial conditions. Channel resources below the full pool level (i.e., within the Fluctuation Zone) experience repeated inundations and alternate from fluvial to lentic conditions.

5.1 CHANNEL RESOURCES ABOVE LAKE OROVILLE

One of the common effects resulting from reservoir construction is alteration of the tributary stream channels upstream of the reservoir. These effects are caused by changes in base level and sediment carrying capacity and can result in sediment accumulations in the tributary channels, and deposition of sediment deltas at the reservoir/stream interface. The channel conditions in the branches of the Feather River above Lake Oroville were examined to evaluate whether Oroville Dam has impacted channel resources upstream of the reservoir.

5.1.1 Stream Classification

Initial stream classification was performed at Rosgen Level I, geomorphic characterization (Rosgen, 1994). The forks of the Feather River above Lake Oroville are classified as Type B streams with some sections displaying a Type A morphology. Type B streams are moderately entrenched with moderate slope and have a riffle or rapids bed morphology with pools and are very stable in plan and profile. All four forks exhibited bedrock control. Type A streams are generally steep and bedrock or boulder bedded with step-pool morphology.

The streams were further classified into mesohabitat types. Meso-(or middle)-habitat typing is the classification of the stream into the elements such as riffle, pool, run, or glide.

5.1.1.1 Methodology

Mapping consisted of delineating river segments using the mesohabitat classification approach as developed by the Surface Water Resources, Inc. (SWRI) for study plan SP-F3.1 (see Table 5.1-1). Some mesohabitat types were further differentiated based on California Department of Fish and Game California Salmonid Stream Habitat Restoration Manual, Part III, Habitat Inventory Methods (Flosi et al, 1997). Habitat type lengths, widths, average depths, substrate quality, spawning gravel quality, and cover type were noted. Length and width measurements were obtained using a laser rangefinder. Depth measurements were made with a stadia rod. Instream cover type was based on the codes developed by DFG and are based on the criteria shown in Table 5.1-2.

Table 5.1-1. Mesohabitat Definitions

Habitat Unit	Defining Characteristics
Cascade	Very steep riffle habitats, consisting of alternating small waterfalls and shallow pools, generally with bedrock or boulder substrate
Riffle	Typically shallow reaches with swiftly flowing, turbulent water; sometimes have partially exposed substrate, typically composed of cobble; small, breaking surface waves are a good indicator
Run	Swift flowing reaches with little surface agitation and no major flow obstructions; may appear as flooded riffles; similar to glides but shallower and with less uniform bottom surface; typical substrate consists of gravel, cobble, and boulders
Pool	Relatively deep with fine-grained substrates; relatively low gradient with relatively low water velocities; tranquil; section controlled
Glide	Uniform channel bottoms with moderate to low flow velocities and little turbulence; substrate is variable; swift flowing but less turbulent and deeper than riffles; deeper and more uniform bottom than runs
Backwater	Pool formed outside or at the margins of the main channel; exhibit little to no flow velocity; often elongate with long axis parallel to the main river channel, but lacking flow input to the upstream end of the backwater; water inside the backwater pools is effectively dammed by adjacent main channel water; usually deepest at the point closest to main channel flow; substrate usually consists of fines

Table 5.1-2. Cover Code Descriptions

Cover Code	Description
A	No apparent cover
B	Small to medium instream objects/woody debris (<31 cm or 1 ft. in diameter)
C	Large instream objects/woody debris (>31cm or 1 ft. in diameter)
D	Overhead Objects
E	Submerged aquatic vegetation
F	Undercut bank

Mesohabitat maps (Appendix B) were prepared for the West Branch and Middle Fork upstream of the reservoir. Mapping on the West Branch included a portion of channel above the Miocene Dam fish barrier because of easier accessibility and similarity with habitat below Miocene Dam. Fish passage barriers on the North Fork and South Fork (Big Bend Dam and Ponderosa Dam, respectively) precluded mesohabitat mapping upstream of the barriers. Mesohabitat maps were prepared for the West Branch, North Fork, Middle Fork, and South Fork within the upper portion of the reservoir Fluctuation Zone and will be discussed in Section 5.2 (Channel Resources Within the Fluctuation Zone).

Portions of the West Branch and Middle Fork have very steep, barren, rocky stream banks. In addition, river flow conditions in some of these same areas are very swift and treacherous. These unsafe conditions prevented staff from accessing some upstream portions. Mesohabitat types within the areas that were inaccessible were mapped in stereo from color aerial photography or from black-and-white digitally ortho-rectified quarter quads (DOQQs). DOQQs were used only outside of the color aerial photo coverage. Portions of the Middle Fork were mapped in the field, from aerial photography flown in April 1996, and from DOQQs. The West Branch was mapped based on field observations.

5.1.1.2 Study Results

<u>**5.1.1.2.1 West Branch**</u>

Mesohabitat along the West Branch above Lake Oroville was field mapped in sections: 1) from the bridge on Jordan Hill Rd. to approximately two miles below Miocene dam, 2) from 49er Gulch downstream approximately 0.75 miles; 3) from the head of the lake at elevation 900 feet upstream to the limit of access. Total mapped channel length was approximately 15,300 feet.

The reservoir behind Miocene Dam is almost completely full of sediment (Photo 5.1-1). The dam no longer functions as a significant sediment trap; clastics up to medium cobble-size appear to pass over the dam. A deep plunge pool occurs immediately downstream of Miocene Dam, ranging in depth from 5 to over 20 feet. The height of the dam above the pool is approximately 12 feet (Photo 5.1-2). Miocene Dam is maintained by P.G. & E. and diverts approximately 25 to 35 cfs into Miocene Ditch. In-stream gages on the West Branch near Miocene Dam are non-existent; however, on the day of the field investigation, it appeared that over half of the total volume of flow was diverted in to the Miocene Ditch.

A wide range of habitat types occur along the West Branch above the reservoir footprint with pool types predominating at 52%, run types at 24%, riffles/glides at 15% and cascades at 5% (Table 5.1-3 and Figure 5.1-1). The remaining 4% comprised the reach occupied by Miocene Reservoir. Photo 5.1-3 shows the typical habitat downstream from the Jordan Hill Road crossing, with two long pools separated by 250 feet of step run and 100 feet of riffles. Photo 5.1-4 shows a pool merging into a step run downstream from Miocene Dam. Flow through this reach was estimated at about 15 cfs. Spawning gravel quality was generally assessed as “good to excellent”.

Table 5.1-3. Habitat Types, West Branch, above reservoir footprint.

Habitat Type	Total Length (ft)	Percentage of Each Habitat
Reservoir	650	4%
Degraded Habitat	0	0%
Pool	5,734	37%
Complex Pool	1,250	8%
Junction Pool	0	0%
Plunge Pool	0	0%
Step Pool	980	6%
Glide	630	4%
Riffle	1,460	10%
High Gradient Riffle	210	1%
Run	865	6%
Boulder Run	440	3%
Step Run	2,327	15%
Step	25	0%
Chute	0	0%
Cascade	745	5%
Total	**15,316**	**100%**

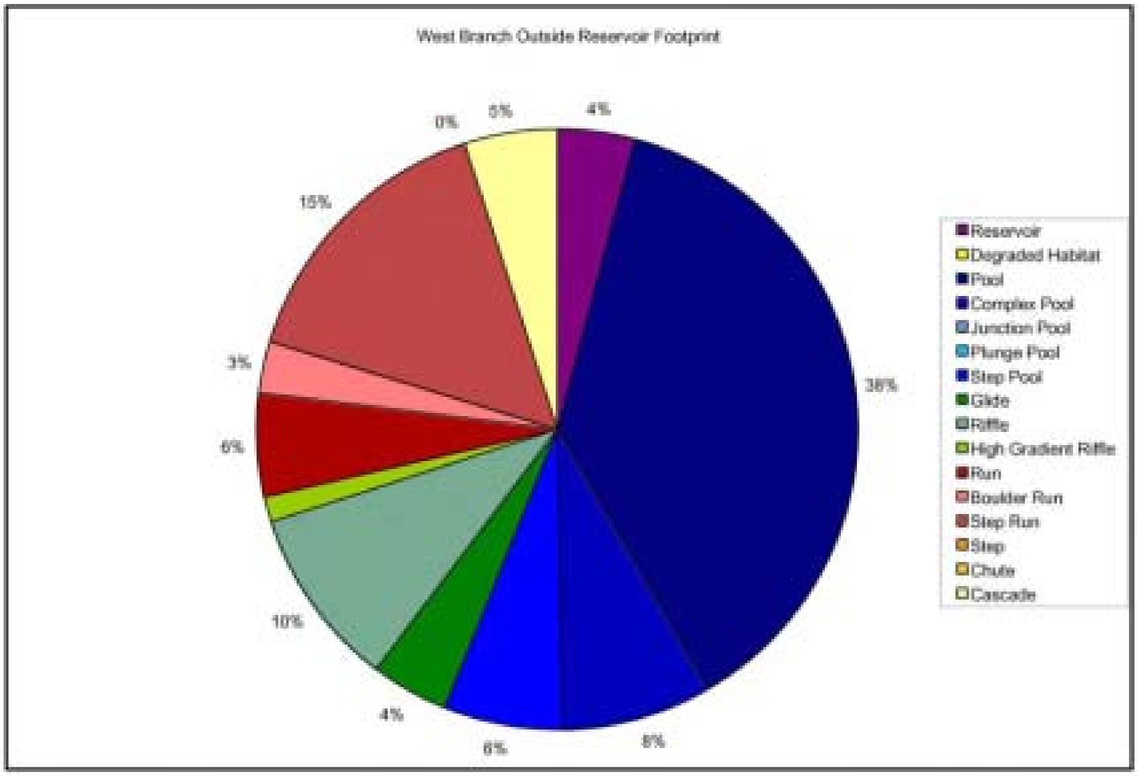


Figure 5.1-1. Relative percentages of habitat types, West Branch, above reservoir footprint.

The remainder of the West Branch that was not classified passes through rocks of similar geology and at a similar gradient as the reaches that have been classified. It is therefore reasonable to assume that the rest of the stream has similar habitat as the portion that has been classified.

5.1.1.2.1 Middle Fork

Mesohabitat typing upstream of the reservoir maximum elevation was performed in the field from the mouth of Fall Creek upstream approximately 0.75 miles to the limit of access. The remainder up to Curtain Falls was accomplished by examining aerial photos from April, 1996 and from DOQQs

The typed reaches were about 40% pools, 41% high gradient riffles and riffles, 9% runs and boulder runs, and 10% cascades. (Table 5.1-4 and Figure 5.1-2). Widths, average depths, substrate types, gravel quality, and cover code were not interpreted from the aerial photos or DOQQs.

Table 5.1-4. Habitat Types, Middle Fork, above reservoir footprint.

Habitat Type	Total Length (ft)	Percentage of Each Habitat
Reservoir	0	0%
Degraded Habitat	0	0%
Pool	5,594	40%
Complex Pool	0	0%
Junction Pool	0	0%
Plunge Pool	0	0%
Step Pool	0	0%
Glide	0	0%
Riffle	0	0%
High Gradient Riffle	5,806	41%
Run	0	0%
Boulder Run	1,230	9%
Step Run	0	0%
Step	0	0%
Chute	206	1%
Cascade	1,317	9%
Total	**14,153**	**100%**

Photo 5.1-5 shows a portion of the Middle Fork approximately 0.5 miles upstream from the reservoir with two moderately deep pools separated by a high gradient riffle. Spawning gravel, where present, was rated as “good to excellent”. There was a notable lack of spawning gravel in pool tail-out portions (Photo 5.1-6). Gravel was present in mid-pool locations (Photo 5.1-7) and in scattered locations along the channel edges (Photo 5.1-8).

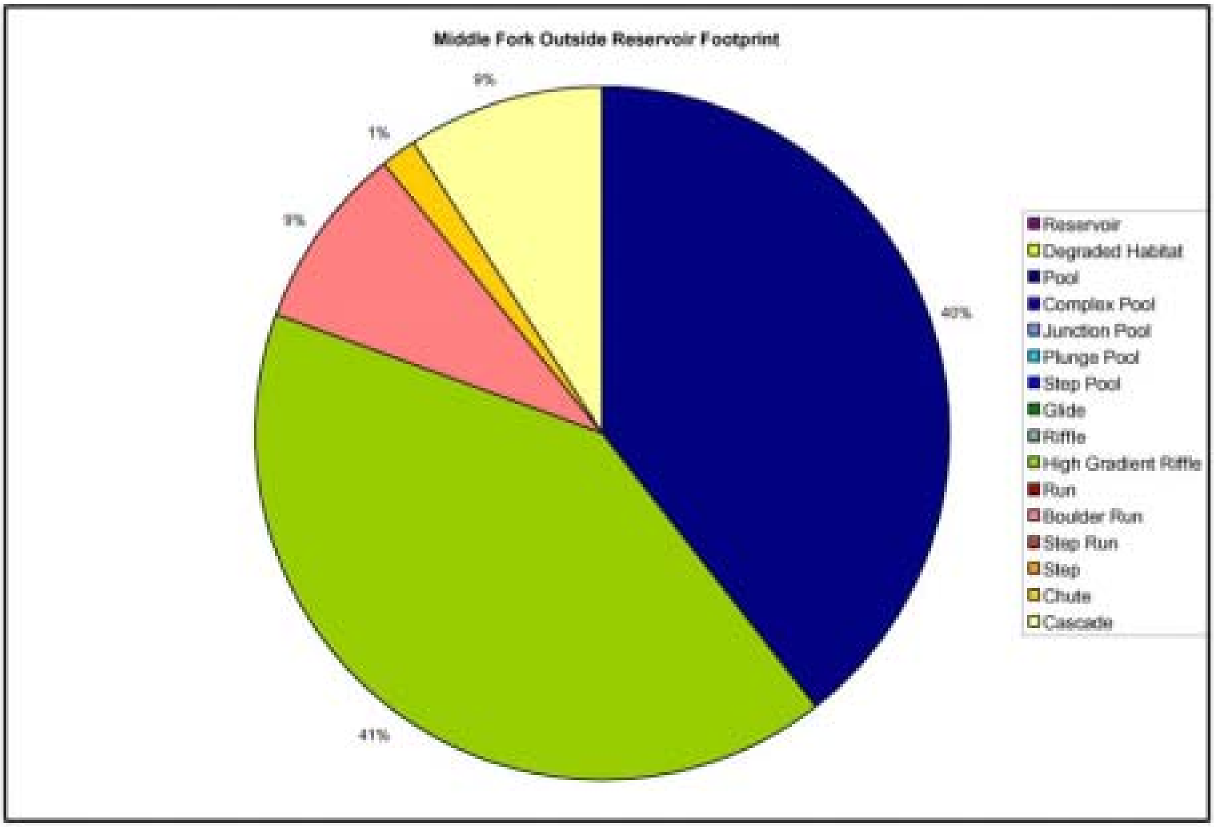


Figure 5.1-2. Relative percentages of habitat types, Middle Fork, above reservoir footprint.

5.1.2 Sediment Characterization and Cross-section Study

5.1.2.1 Methodology

Cross-sections were to be surveyed at impacted areas identified as having a deleterious buildup of sediment or excessive erosion. The spacing and level of detail was to be selected based on the magnitude of the impacted area. The ability to perform cross-section studies was severely limited by access constraints. Effects on the North Fork and South Fork above the reservoir are controlled by Big Bend and Ponderosa dams respectively, and impacts from the project to these tributaries would be obscured by the effects from these two dams. The Middle Fork and West Branch are controlled by bedrock reaches immediately above reservoir full pool and show no effects of sedimentation or erosion that could be attributed to the project. One area of the West Branch at Miocene Dam that is accessible was chosen for the cross-section study. This area shows some sediment starvation effects from Miocene Dam and is an indicator for conditions in the West Branch pertaining to salmonid habitat.

Six stream cross-sections were surveyed approximately 0.25 miles below Miocene Dam along a 350 foot section. The section included a pool-riffle-run sequence. Two Wolman Pebble Counts and a bulk gravel analysis were conducted.

Cross-section locations, cross-section profiles, gravel sample locations, and stream characteristics are shown in Plate 5.1-1. Surface and sub-surface gravel (BS-WB-2) were sampled on a mid-stream gravel bar between Cross-section #5 and Cross-section #6 (Photo 5.1-9). A Wolman Count (WC #1) of the surface gravel was also taken on the mid-stream gravel bar. A second Wolman Count (WC #2) was taken on the coarse gravel bank between Cross-section #3 and Cross-section #4 (Photo 5.1-10). Grain-size distribution curves of the sieved gravel samples and Wolman Counts are shown in Figures 5.1-3, 5.1-4, and 5.1-5.

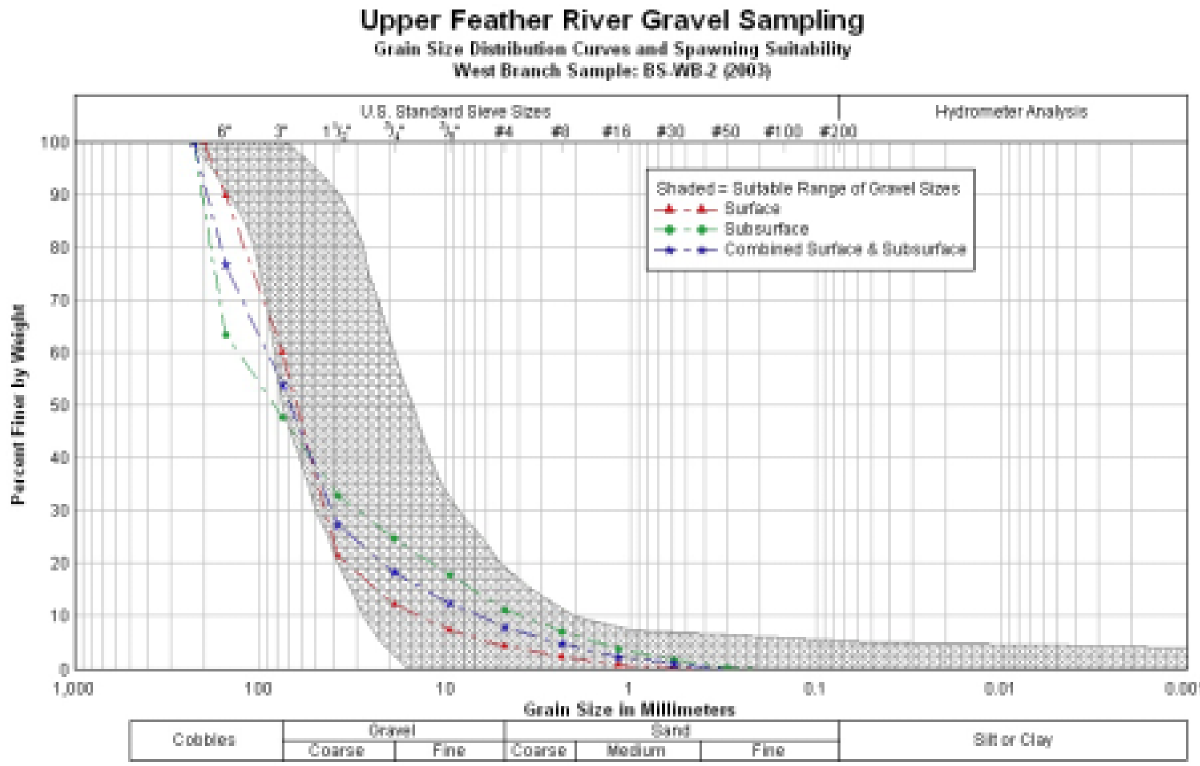


Figure 5.1-3. BS-WB-2 -- Grain Size Cumulative Distribution

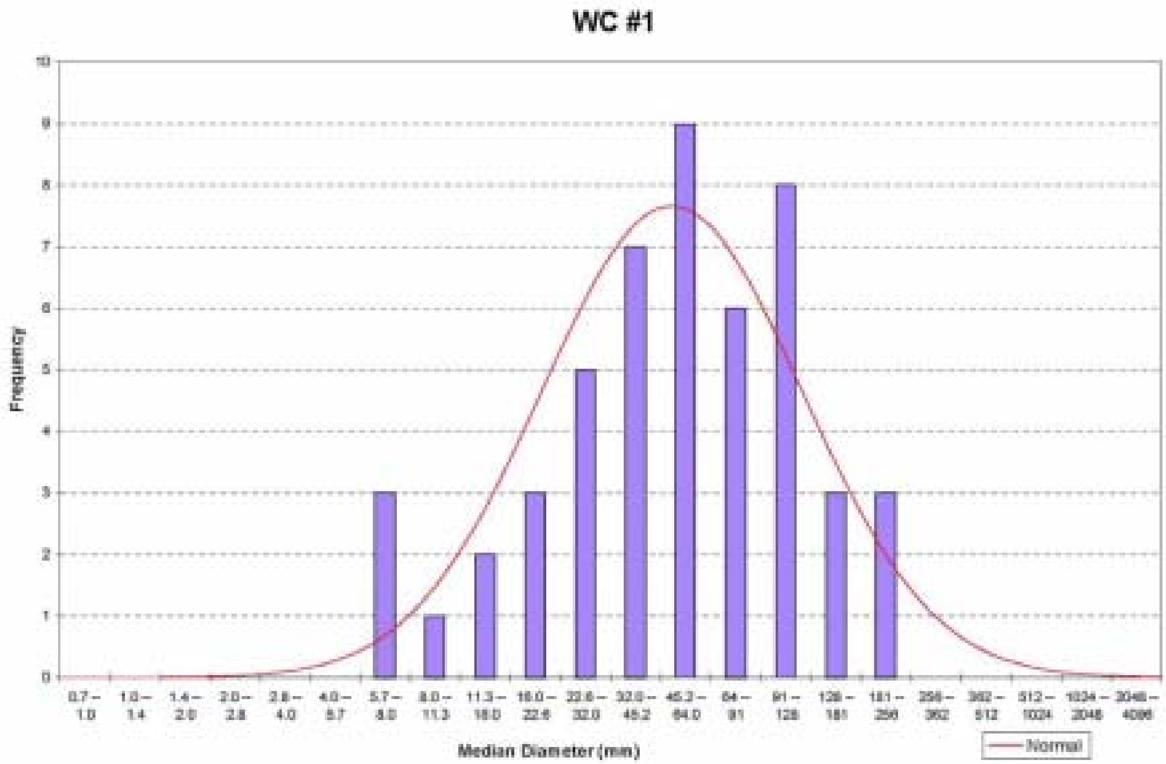


Figure 5.1-4. WC#1 -- Grain Size Distribution

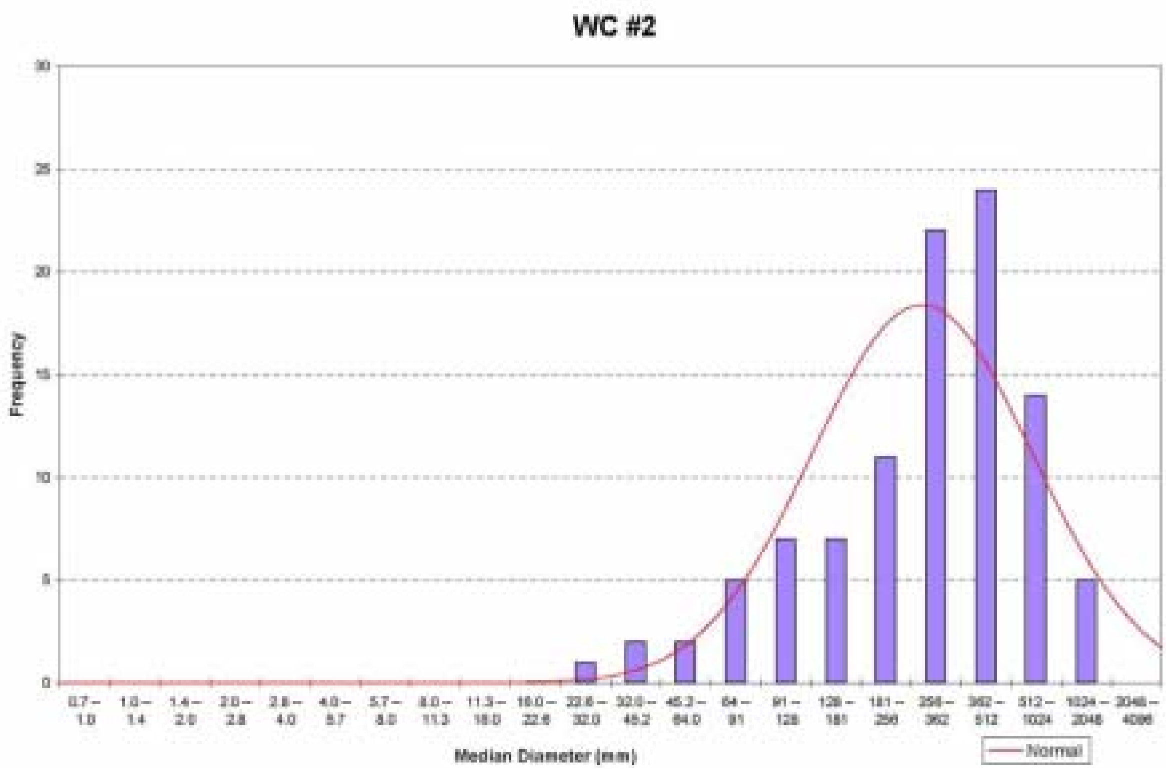


Figure 5.1-5. WC#2 -- Grain Size Distribution

5.1.2.2 Study Results

The stream thalweg drops 8.1 feet between Cross-section #1 and Cross-section #6 over a length of 352 feet (i.e., 0.023 foot drop per lineal foot). Stream banks are predominantly very coarse gravels to large boulders. Very little fine gravel or sand is present in this area, probably because of past sediment trapping by the upstream Miocene Dam. The upstream portion of the left bank is well defined by a serpentine bed-rock outcrop. The downstream portion of the left bank is predominantly large boulders thickly covered with vegetation dominated by alders. The right bank is fairly-well defined with a strip of willow habitat, then alders.

5.2 CHANNEL RESOURCES WITHIN FLUCTUATION ZONE

As indicated in section 1.3.2, from October through March, the maximum allowable storage limit (point at which specific flood release would have to be made) varies from about 2.8 to 3.2 maf to ensure adequate space in Lake Oroville to handle flood flows. This corresponds to a potential reservoir water surface elevation fluctuation between 848.5 and 900 feet on any given year. Consequently, at least annually and during dry periods the tributaries below elevation 900 ft are available as stream habitat. These stream reaches were therefore assessed for suitability as salmonid habitat.

During the time of the study, abundant sediment deposits were not present above the 700 to 720 feet elevation within the reservoir footprint. However, extensive sediment deposits were identified in all four major tributaries at about 720 feet elevation and below. These deposits, referred to as “sediment wedges” are discussed further in Section 6.0. Mesohabitat mapping was not performed on the steam segments flowing across the sediment wedges.

5.2.1 Stream Classification

5.2.1.1 Methodology

Mesohabitat typing, including cover code and spawning gravel assessment was conducted on all four main tributaries within the Fluctuation Zone from above the sediment wedges upstream to full pool level (900 feet). Stream classification methodology was the same as that described in Section 5.1.1.1

5.2.1.2 Study Results

5.2.1.2.1 West Branch of the North Fork

A large sediment wedge on the West Branch occupied the river channel from Cape Horn to approximately 0.75 miles downstream (Photo 5.2-1). The sediment wedge is composed primarily of medium to coarse sand with minor small pebbles and some cobbles. Fine silt covered the elevated portions of the wedge that have not been reworked by the river current as the lake elevation lowered (Photo 5.2-2).

Mesohabitat typing within the reservoir began at the upper terminus of the sediment wedge where the river channel narrows near Cape Horn and extended upstream to the mouth of Concow Creek during 2002, and from Concow Creek upstream to the limit of access during 2003. From there to the 900 ft elevation the mapping was done from 1:4800 scale air photos. These photos are detailed enough to allow estimates of water depth and substrate composition.

The lower portion is predominantly runs and riffles in the narrow gorge upstream of Cape Horn. Pools interspersed with runs and/or riffles become more common as the river channel widens and gradient becomes less steep. A very notable feature is a deeply incised inner gorge about 0.25 miles downstream of Concow Creek and continuing downstream about 0.25 miles (Photos 5.2-3 and 5.2-4) containing two long pools separated by 140-foot long cobble riffle sequence. The downstream pool has an average depth of about 20 feet. The substrates in both pools are bedrock or boulders covered by silt.

The mesohabitat for the West Branch within the reservoir Fluctuation Zone includes 70% pools, 8% riffles/glides 12% runs, and 10% cascades (Table 5.2-1 and Figure 5.2-1). Spawning gravel quality was generally rated as “good” (Photo 5.2-5), however lower portions have an excessive build-up of silt on the gravel bars (Photo 5.2-6)

Table 5.2-1. Habitat Types, West Branch, within reservoir footprint.

Habitat Type	Total Length (ft)	Percentage of Each Habitat
Reservoir	0	0%
Degraded Habitat	0	0%
Pool	4,894	46.33%
Complex Pool	1,060	10%
Junction Pool	100	1%
Plunge Pool	45	0%
Step Pool	1,265	12%
Glide	250	2%
Riffle	420	4%
High Gradient Riffle	245	2%
Run	365	3%
Boulder Run	745	7%
Step Run	120	1%
Step	0	0%
Chute	0	0%
Cascade	1,055	10%
Total	**10,564**	**100%**

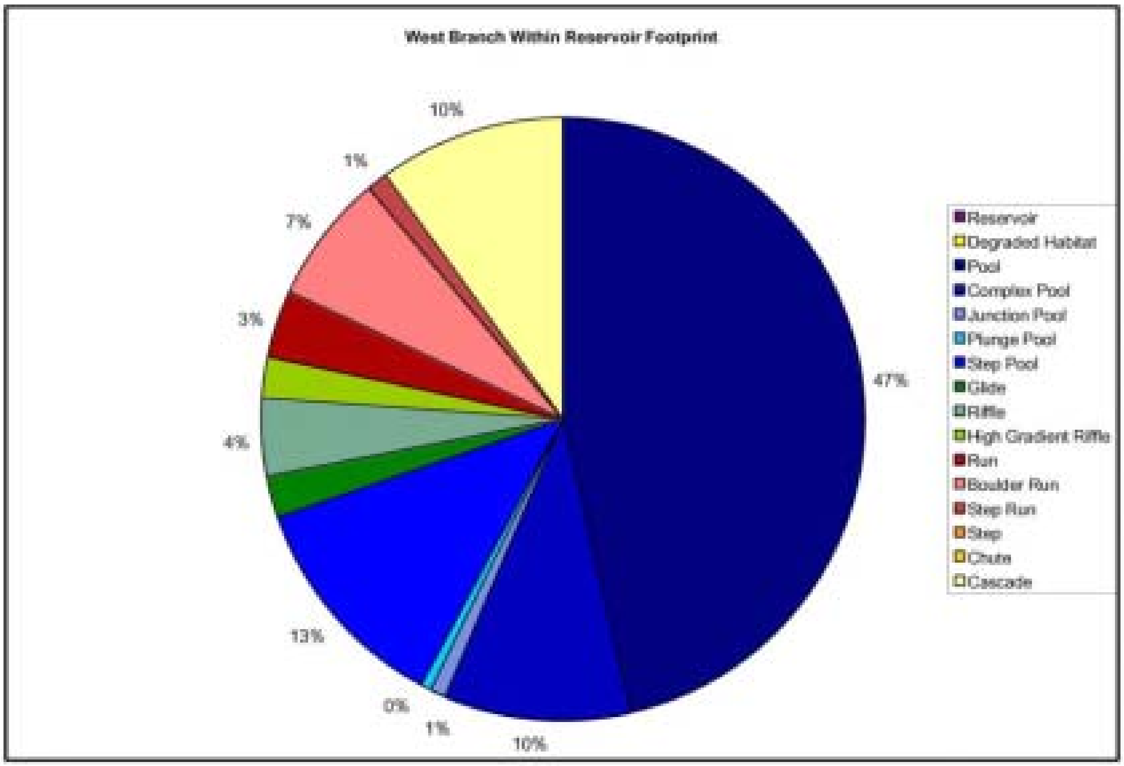


Figure 5.2-1. Relative percentages of habitat types, West Branch, within reservoir footprint.

5.2.1.2.2 North Fork

Flow in the North Fork is determined by the operating requirements of Poe Powerhouse and can fluctuate widely over a short time frame. The capacity of the Poe Powerhouse is 3,900 cfs and flow in the river has a daily range of less than 500 cfs up to greater than 3,900 cfs. Photos 5.2 -7 and 5.2-8 show the amount of flow variation over the Big Bend Dam in about four hours. During high flows, water occupies the entire river channel, along most sections (Photo 5.2-9). The fluctuating flows and difficult bank access precluded field mapping of habitat types.

Mesohabitat mapping was based on aerial photography flown in April 1996. Flow volume at the time of the photos is unknown, because there is no flow gage on the river below Poe Powerhouse. Habitat mapping was completed for the river sections starting at Big Bend Dam downstream about 4.5 miles to the reservoir/stream interface.

The habitat type was predominated by runs (75%) and high gradient riffles/riffles (22%) (Table 5.2-2). Only 3% of the typed reach was classified as pool. The high variability in flows made the habitat typing difficult. For example, Photo 5.2-10 shows sections that were typed as runs or high gradient riffles based on the 1996 aerial photography, but may actually be a series of pools, riffles, and runs at a lower flow.

Table 5.2-2. Habitat Types, North Fork, within reservoir footprint.

Habitat Type	Total Length (ft)	Percentage of Each Habitat
Reservoir	0	0%
Degraded Habitat	0	0%
Pool	654	3%
Complex Pool	0	0%
Junction Pool	0	0%
Plunge Pool	0	0%
Step Pool	0	0%
Glide	0	0%
Riffle	420	2%
High Gradient Riffle	4,956	21%
Run	17,898	74%
Boulder Run	0	0%
Step Run	0	0%
Step	0	0%
Chute	0	0%
Cascade	0	0%
Total	**23,928**	**100%**

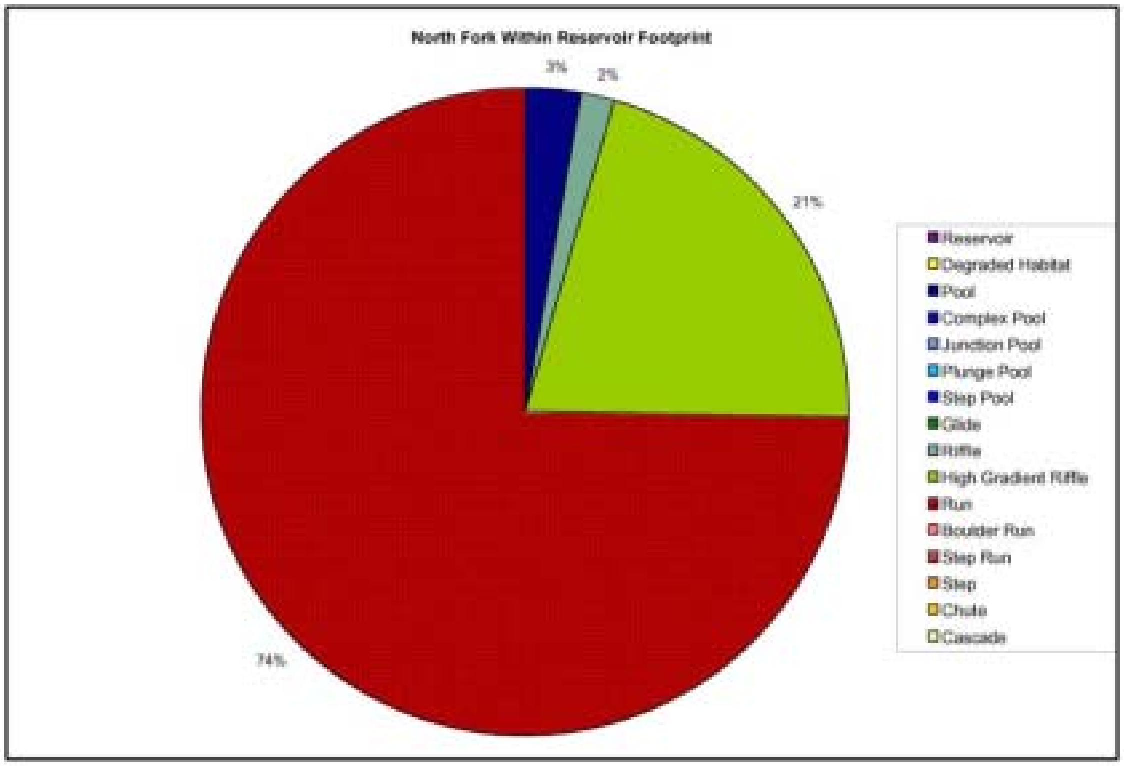


Figure 5.2-2. Relative percentages of habitat types, North Fork, within reservoir footprint.

5.2.1.2.3 Middle Fork

A lower portion of the Middle Fork within the Fluctuation Zone was typed in October 2002, when the reservoir elevation was about 710 feet. A sediment wedge was encountered about 0.25 miles upstream of Cross-Section MF-6, and continued upstream approximately 6,500 feet (Photo 5.2-11) to a point where the channel narrows and gravel, cobbles, and bedrock comprise the bulk of the stream substrate. Mesohabitat typing began at this point and continued upriver about 3,600 feet until access difficulties (Photo 5.2-12) prevented further typing upstream. An upper portion of the Middle Fork within the Fluctuation Zone was field typed from elevation 800 ft. upstream to the limit of access in fall 2003. The remainder of the Middle Fork within the Fluctuation Zone was typed from of the 2001 1:4800 scale photos. These photos are detailed enough to allow estimates of water depth and substrate composition when compared to the field typed sections.

The field-typed stretch is composed of about 24% pools, 25% glides or riffles, 44% runs, and 7% cascades (Table 5.2-3 and Figure 5.2-3). Substrate included fine to coarse gravel with some cobbles and boulders. Abundant cobble to sand sediments line the actual river channel (Photo 5.2-13); these deposits are most likely remnants from when the sediment wedge resided higher up in the reservoir footprint. The remnant material provides abundant substrate material for the Middle Fork in the Fluctuation Zone. Spawning gravel quality along the entire typed stretch was rated “good to excellent” (Photo 5.2-14).

Between the two sections typed in the field the air photos show a long section of stream with a gravel or cobble bottom. Observations of this section looking into the lake from a boat in 2003 indicated a gravel to cobble lag deposit from the reworking of the sediment wedge occupying the bottom of the channel.

Table 5.2-3. Habitat Types, Middle Fork, within reservoir footprint.

Habitat Type	Total Length (ft)	Percentage of Each Habitat
Reservoir	0	0%
Degraded Habitat	0	0%
Pool	3,226	24%
Complex Pool	0	0%
Junction Pool	0	0%
Plunge Pool	0	0%
Step Pool	0	0%
Glide	1,224	9%
Riffle	674	5%
High Gradient Riffle	1,455	11%
Run	3,454	27%
Boulder Run	2,270	17%
Step Run	0	0%
Step	0	0%
Chute	0	0%
Cascade	940	7%
Total	**13,243**	**100%**

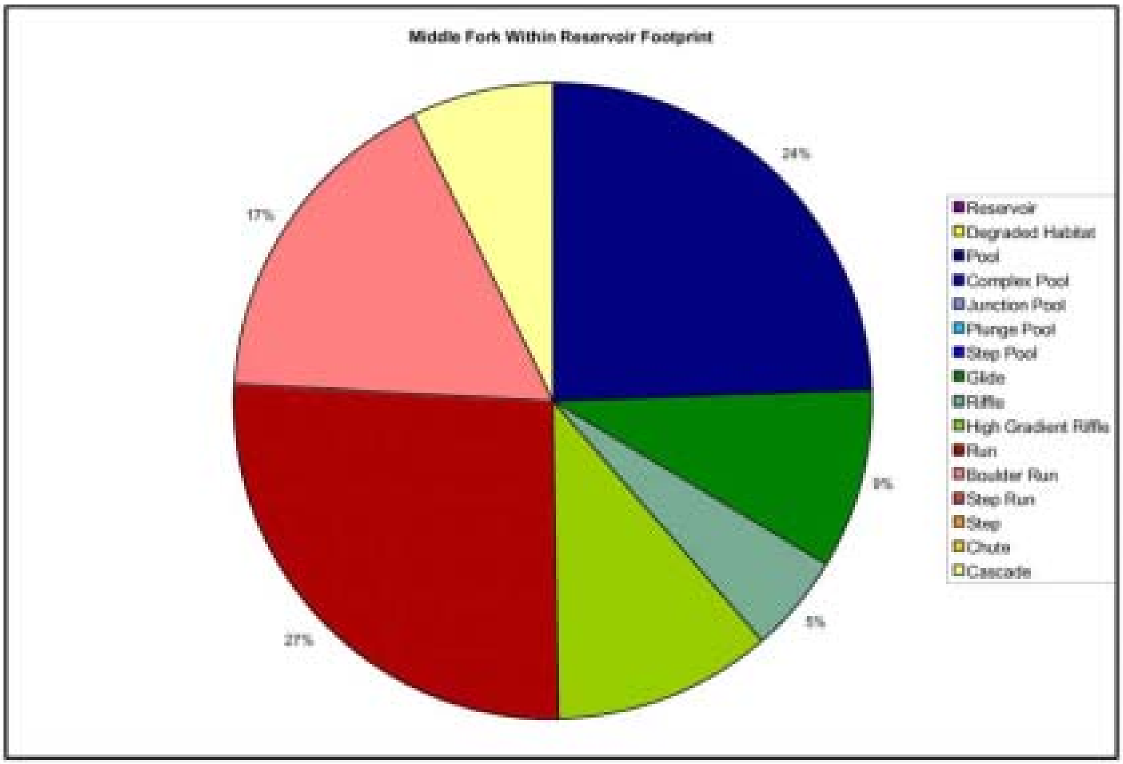


Figure 5.2-3. Relative percentages of habitat types, Middle Fork, within reservoir footprint.

5.2.1.2.4 South Fork

Mesohabitat along the South Fork was mapped within the Fluctuation Zone from Ponderosa Dam downstream about 8,500 feet in October, 2002 Flows fluctuate widely out of Ponderosa Dam based on operating criteria for the South Fork Feather Water and Power powerhouse feeding into Ponderosa Lake. Photo 5.2-15 shows Ponderosa Dam spilling water into the South Fork in late afternoon; flow is estimated at 50 cfs. However, flow earlier on the same day was estimated at 5 cfs. Photo 5.2-16 shows a large boulder on the right side of the stream (looking downstream). This is the same large boulder on the left side of the stream (looking upstream) in the previous photo, showing a two to three foot stream depth fluctuation. Because of the varying flows and an obvious high water stain, it was decided to type the stream sections based on a higher flow condition than the 5 cfs flow encountered.

The typed sections were about 34% pools, 41% glides/riffles, 10% runs and 4% cascades (Table 5.2-4 and Figure 5.2-4). In addition, an 11% portion on the downstream end was classified as degraded habitat because it was considered to be a remnant of the sediment wedge on the South Fork. Photo 5.2-17 shows a typical pool 4 feet deep and 30 feet wide. Substrate in this section showed a lack of suitable spawning gravel. Sucker Run Creek joins the South Fork approximately 0.25 miles downstream from Ponderosa Dam and was flowing at about 5 cfs at the time of typing. Gravel quantities appear nearly depleted on the South Fork above Sucker Run Creek, but increase downstream due to the gravel contribution from Sucker Run Creek. Photo 5.2-18 shows a section immediately downstream from Sucker Run Creek; substrate was sand to cobble. Spawning gravel quality was rated as “poor” above the confluence of Sucker Run Creek and South Fork, and “good to excellent” below the confluence.

Many of the pools are bedrock controlled with a steep run or cascade at their downstream ends. Photo 5.2-19 shows a pool with a sand and gravel substrate flowing into a bedrock controlled cascade. Lower sections of the South Fork have substrates with increasing proportions of fine to coarse sand. The increase in sand content is probably due to the erosion of sediment wedge material lining the sides of the channel as seen in Photo 5.2-20.

Table 5.2-4. Habitat Types, South Fork, within reservoir footprint.

Habitat Type	Total Length (ft)	Percentage of Each Habitat
Reservoir	0	0%
Degraded Habitat	900	11%
Pool	2,554	30%
Complex Pool	345	4%
Junction Pool	0	0%
Plunge Pool	0	0%
Step Pool	0	0%
Glide	626	7%
Riffle	2,903	34%
High Gradient Riffle	0	0%
Run	600	7%
Boulder Run	292	3%
Step Run	0	0%
Step	0	0%
Chute	0	0%
Cascade	317	4%
Total	**8,537**	**100%**

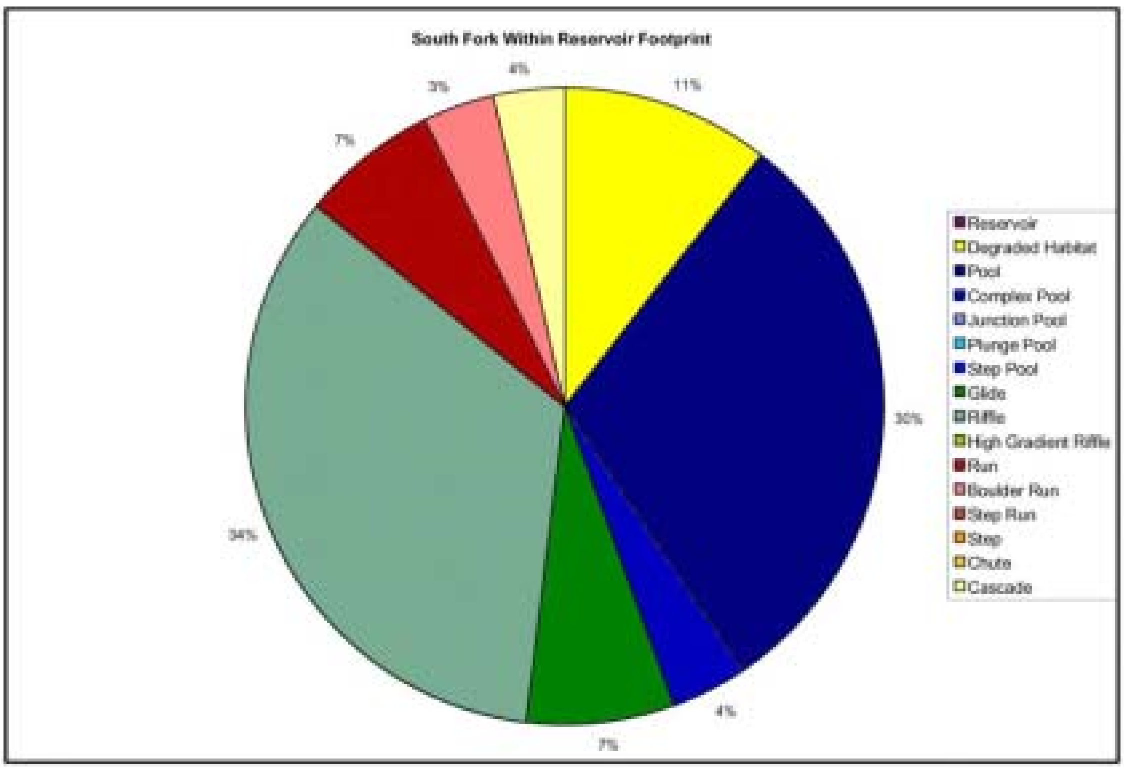


Figure 5.2-4. Relative percentages of habitat types, South Fork, within reservoir footprint.

5.2.2 Sediment Characterization

5.2.2.1 Methodology

Representative areas at the riffles were to be analyzed using bulk gravel sampling and surface sampling techniques to determine the surface and substrate quality of spawning gravel. Gradation curves for each riffle would be prepared. These data are particularly important in evaluating project effects on fish and the riparian community. Access problems precluded much of this work from occurring. During the entire 2002 field season the sediment wedges prevented any access to the main tributaries within the Fluctuation Zone. Flow changes in the North Fork prevented safe access to any appropriate gravel resources. Access to the West Branch and Middle Fork was by boat only. Gravel sampling on the Middle Fork near the reservoir/stream interface was attempted but dropping reservoir levels barred access to suitable gravel locations. Gravel sampling on the West Branch near the reservoir/stream interface was accomplished in spring 2003. Based on geomorphic observations of the upstream substrate typing, this one sample could be construed to be representative of available gravel in the West Branch

5.2.2.2 Study Results Stream Gravel Analysis

Surface and sub-surface gravel samples (BS-WB-1) were taken on a small gravel bar on the West Branch within the Fluctuation Zone approximately 500 downstream from the reservoir/stream interface at the 890 foot elevation (Photo 5.2-21) A Wolman Count (WC #3) of the surface gravel was also taken on the gravel bar. Grain-size distribution curves of the sieved gravel samples and Wolman Counts are shown in Figures 5.2-5, and 5.2-6.

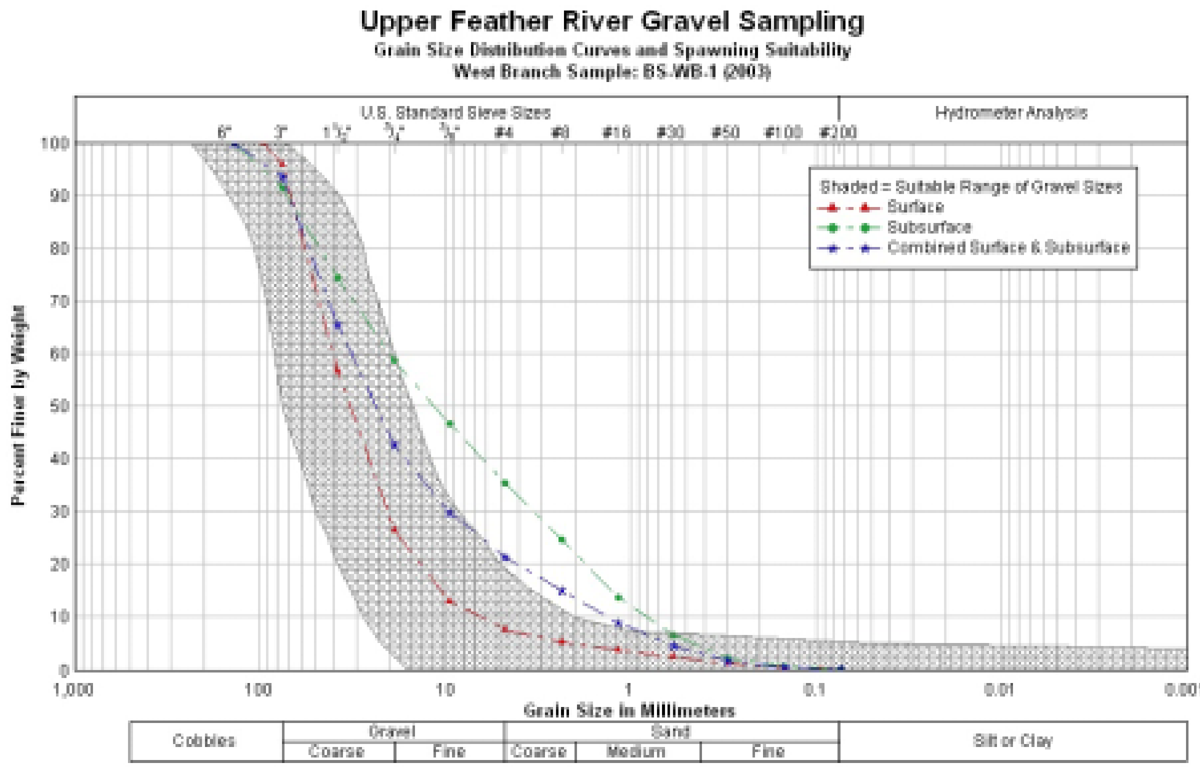


Figure 5.2-5. BS-WB-1 -- Grain Size Cumulative Distribution

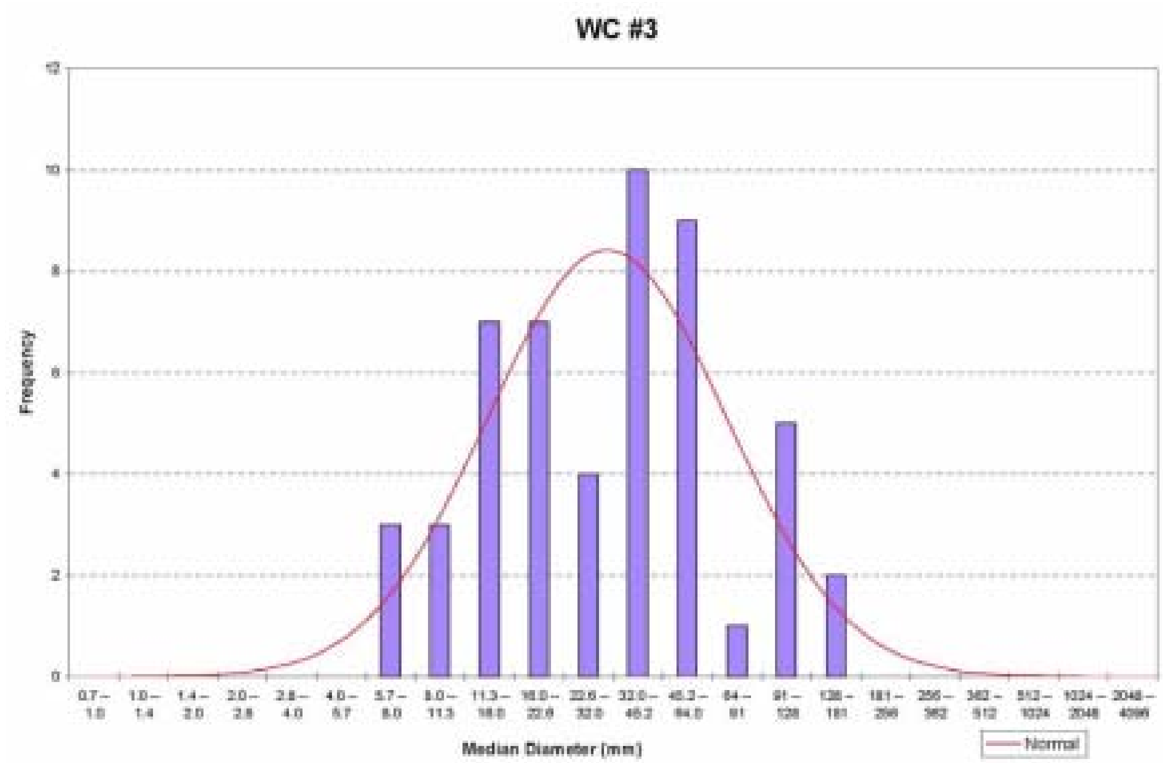


Figure 5.2-6. WC#3 -- Grain Size Distribution

5.3 CONCLUSIONS

This study plan assessed geomorphological conditions and provided habitat typing information for the SP-F3 study plan. Professional biological assessment of habitat is beyond the scope of this study plan. However, based on the geomorphological assessment and habitat typing of the West Branch and the Middle Fork tributaries above the full pool level (i.e., 900 feet) of Lake Oroville, impacts due to project operations were not observed. Fluctuating water levels discourage substantial delta and sediment deposits above the 900 foot level.

At the time of the field investigation for this study, upper portions of the fluctuation zone were exposed to fluvial (as opposed to lentic) conditions. Based on the geomorphological assessment and habitat typing of the four main tributaries within the fluctuation zone, the following preliminary conclusions are presented:

- The West Branch has in-stream gravel strata generally considered suitable for salmon spawning habitat in the upper portion of the Fluctuation Zone but silt accumulation on the downstream portions causes a degradation in spawning gravel quality
- Salmon spawning habitat in the North Fork is affected because of daily fluctuating flows from upstream hydroelectric facilities.
- The Middle Fork has abundant gravel sources from remnant sediment wedge lag deposits.
- The South Fork is gravel-starved above Sucker Run Creek and is subject to flow variations due to Ponderosa Dam. Spawning gravel quality improves downstream of Sucker Run Creek but gradually becomes sandier from remnant sediment wedge deposits.

Future flooding events (similar to 1997) will cause temporary episodic impacts to salmonid habitat in the upper portions of the Fluctuation Zone (from 800 ft to 900 ft) if floods occur at full pool level.

6.0 TASK 3—RE-SURVEY RESERVOIR CROSS-SECTIONS AND DETERMINE SEDIMENT IN STORAGE

This task consisted of evaluating the amount of sediment captured by Lake Oroville. Cross-sections were previously surveyed in 1971, and 1993/94. Since the previous surveys, a large storm event in January 1997 delivered a substantial amount of new sediment into the lake. The 24 existing cross-sections were re-surveyed as part of this study plan to determine the total amount of sediment deposited to date. In addition, current technology utilizing the Global Position Satellite (GPS) system allowed for performing a bathymetric survey along the thalwegs of the four major tributaries. These thalweg surveys provided a validation of the cross-section survey results and facilitated locating substantial sediment deposits in the upper arms of the major tributaries.

6.1 RE-SURVEY RESERVOIR CROSS-SECTIONS

6.1.1 Methodology

Most of the cross-section endpoint monuments placed during the previous investigations were located and inspected beginning in spring 2002. Several endpoint monuments were missing since the previous cross-section survey in 1994; their locations were derived based on monumented back-sites and previous survey field notes. One cross-section (MF-8) did not have a back-site monument; its missing endpoint location was based on a “best guess” section line perpendicular to the stream channel. Table 6.1-1 presents the cross-section names, lengths, and survey dates. The table also contains data on the endpoint coordinates, elevations, and endpoint monument characteristics.

All endpoints were surveyed using real-time kinematic (RTK) Global Positioning System (GPS) equipment or a combination of RTK and conventional total station surveying equipment. The GPS equipment consisted of a Trimble 4000SSI dual frequency receiver base station near the Foreman Creek Day Use Area and Trimble backpack 4700 receiver. Temporary base stations were also established at outlying regions for surveying cross-section endpoints in the upper portions of the lake. Coordinates (i.e., northings and eastings) for each endpoint were recorded in State Plane datum (i.e., NAD83 CCS, Zone 2). Elevations were recorded in NGVD29 datum. Endpoint locations were measured twice with GPS equipment with different satellite configurations to ensure location accuracy to within 0.1 feet. In some cases a radio repeater unit had to be set up between the cross-section location and the base station when the telemetered data from the base station was weak or non-existent. This situation was more prevalent in the mountainous terrain and winding river channels of the upper portion of the lake arms. Conventional total station surveying equipment was used at some locations where overhead vegetation or mountainous terrain rendered the GPS equipment inoperable.

By surveying the cross-section endpoints with GPS equipment, the exact geographical location of the endpoint can be relocated for future sedimentation studies even if the endpoint monuments disappear in the future.

Table 6.1-1. Lake Oroville Cross-Section Descriptions

Section Name	Length (ft.)	Survey Date	End Point Information				
			Name	Northing	Easting	Elev. (ft)	EndPointType/Comments
WB-1	1,416.24	7/23/02	WB1A	2369833	6703395	922.28	Same as NF5B, 1.5" pipe w/ brass cap
			WB1B	2369150	6702155	910.94	1.5" pipe w/ brass cap
WB-2	1,117.00	7/23/2002	WB2A	2370297	6691870	906.85	1.5" pipe w/ brass cap
			WB2B	2369200	6691665	897.15	Calculated position, measured elevation
WB-3	956.12	7/10/2003	WB3A	2373539	6687733	906.66	Disk in yellow-painted rock
			WB3B	2373714	6686793	900.00	1.5" pipe w/ brass cap
WB-4	832.01	7/11/2003	WB4A	2381559	6685442	906.67	Disk in yellow-painted rock
			WB4B	2381252	6684669	898.00	Calculated position, measured elevation
WB-5	510.00	7/12/2003	WB5A	2386271	6686826	898.50	Calculated position, measured elevation
			WB5B	2386136	6686334	922.11	Bolt on pipe in concrete
FR-1	6,790.52	7/15/2002	FR1A	2326621	6714038	901.74	1.5" pipe w/ brass cap
			FR1B	2331611	6709433	904.23	1.5" pipe w/ brass cap
NF-2	2,973.32	7/15/2002	NF2A	2344694	6709810	905.88	1.5" pipe w/ brass cap
			NF2B	2343150	6707269	903.39	1.5" pipe w/ brass cap
NF-3	2,472.40	7/17/2002	NF3A	2352793	6706378	903.85	1.5" pipe w/ brass cap
			NF3B	2353076	6703967	904.21	.75" pipe
NF-4	1,848.61	7/17/2002	NF4A	2361570	6703189	913.25	1.5" pipe w/ brass cap
			NF4B	2361716	6701346	900.49	Disk 50' downstream from marker paddle
NF-5	1,750.95	7/23/2002	NF5A	2368649	6704685	904.29	Disk in rock 4' east of marker paddle
			NF5B	2369833	6703395	922.28	Same as WB1A, 1.5" pipe w/ brass cap
NF-6	1,745.00	7/23/2002	NF6A	2372145	6708365		Calculated
			NF6B	2373875	6708595	910.82	T-Post
NF-7	1,481.57	7/24/2002	NF7A	2370122	6720920	905.02	.75" iron pipe
			NF7B	2371066	6721613	905.44	1.5" pipe w/ brass cap
NF-8	612.00	7/25/2002	NF8A	2376469	6727691	903.43	1.5" pipe w/ brass cap - "very loose"
			NF8B	2376215	6727134		Calculated
NF-9	387.00	7/26/2002	NF9A	2386456	6726612	901.68	1.5" pipe w/ brass cap
			NF9B	2386185	6726336		Calculated
MF-1	1,695.33	7/16/2002	MF1A	2325963	6722383	935.17	1.5" pipe w/ brass cap
			MF1B	2327646	6722585	937.93	1.5" pipe w/ brass cap
MF-2	1,956.00	7/17/2002	MF2A	2330767	6729895	904.19	.75" iron pipe in concrete
			MF2B	2331064	6727962	897.60	Disk in yellow-painted rock
MF-3	1,725.19	7/18/2002	MF3A	2333974	6731875	923.49	1.5" pipe w/ brass cap
			MF3B	2334726	6730150	909.93	1.5" pipe w/ brass cap
MF-4	1,637.54	7/16/2002	MF4A	2335424	6733652	925.34	.75" iron pipe in concrete
			MF4B	2337057	6733536	916.71	.75" iron pipe in concrete
MF-5	1,300.62	7/18/2002	MF5A	2339876	6743703	906.53	T-Post
			MF5B	2340130	6742428	909.02	Disk in rock
MF-6	926.98	8/1/2002	MF6A	2346650	6752267		Calculated
			MF6B	2346971	6753137	905.32	Calculated position, measured elevation

Table 6.1-1. Lake Oroville Cross-Section Descriptions

Section Name	Length (ft.)	Survey Date	End Point Information				
			Name	Northing	Easting	Elev. (ft)	EndPointType/Comments
[redacted]							
MF-7	506.25	8/7/2002	MF7A	2351468	6761507	904.80	Disk in yellow-painted rock
			MF7B	2351564	6761001	931.11	Calculated position, measured elevation
MF-8	297.26	7/24/2003	MF8A	2355083	6762742	899.09	Yellow-painted rock w/ drill hole
			MF8B	2355365	6762649	900.21	Calculated position, measured elevation
SF-1	1,342.18	7/16/2002	SF1A	2323060	6729312	925.05	1.5" pipe w/ brass cap
			SF1B	2324280	6728753	906.47	Disk in rock
SF-2	1,354.16	7/17/2002	SF2A	2320971	6733749	911.51	1.5" pipe w/ brass cap
			SF2B	2322136	6734439	916.66	1.5" pipe w/ brass cap

Cross-section bathymetry was measured from a boat using a Knudsen 320M Survey Echo sounder linked to RTK equipment, while the boat traversed the cross-section trace at approximately 4 miles per hour. This procedure was different from the previous two surveys where bathymetry location data was derived from on-shore survey equipment utilizing a theodolite and electronic distance meter. For this survey, each cross-section was traversed four or more times from shore to shore to ensure complete coverage of the cross-section. The bathymetry data was post-processed in the office and a triangular irregular network (TIN) of survey points was created using AutoDesk Land Desktop software. The actual elevations along the trace of the cross-section were then derived from the contoured surface created from the TIN.

Bathymetry data errors may occur in several ways. The measured depth accuracy is dependent upon bottom irregularities, cone angle of the transducer, and on the angle of the reservoir slope. The steeper slopes are less accurate because of multiple signal reflections from the sloping bank. In general, the most accurate readings are obtained at the bottom of the thalweg where a relatively flat surface has built up due to sedimentation.

Side slope profiles of the cross-sections were measured using a Trimble 4700 backpack RTK unit. Side slope elevations were measured at less than 10 foot intervals and at noticeable slope breaks.

Twenty of the original 24 cross-sections were surveyed and sounded in 2002. The location of the endpoints for the uppermost section in the Middle Fork (MF-8) could not be relocated and was not surveyed or sounded in 2002. In addition, low water conditions and difficult access prevented completion of the study at three sections (WB-3, WB-4, and WB-5) in the upper West Branch. These remaining three West Branch sections were surveyed and sounded in summer, 2003 after Lake Oroville reached full pool level. One endpoint for MF-8 was relocated in 2003 and the section was surveyed and sounded. Figure 6.1-1 shows the location of all 24 cross-sections.

Original cross-section profiles were derived from the DWR mapping that was completed in 1967 from the September 1965 aerial photography. The contour interval of the map sheets is 20 feet. Plates 6.1-1 (index map) and Plates 6.1-2-A through 6.1.2-G show the area of Lake Oroville and the cross-section locations on the 20-foot contour mapping.

Cross-section profiles from the 1971 report and the 1994 report were re-created based on the raw survey data from those investigations. The raw data were used rather than the derived sections in the actual reports. This procedure was used because the cross-section representations in the report had been adjusted to eliminate probable data errors in the bathymetry data.

The four (or three, in the case of WB-2, WB-3, WB-4, WB-5, FR-1, SF-1, and SF-2) cross-section profiles for each section were superimposed over each other with the assumption that all surveys profiles started at Endpoint A (i.e., left-bank endpoint looking downstream). Plates 6.1-3 through 6.1-26 present the cross-section profiles at a vertical and horizontal scale of 1 inch = 200 feet, or greater. These plates also contain a detail of the thalweg portion showing the estimated sediment accumulation in the area of the former river channel. Plates 6.1-27 through 6.1-50 present a map view of each cross-section on the 1967 map base at a scale of 1 inch = 200 feet.

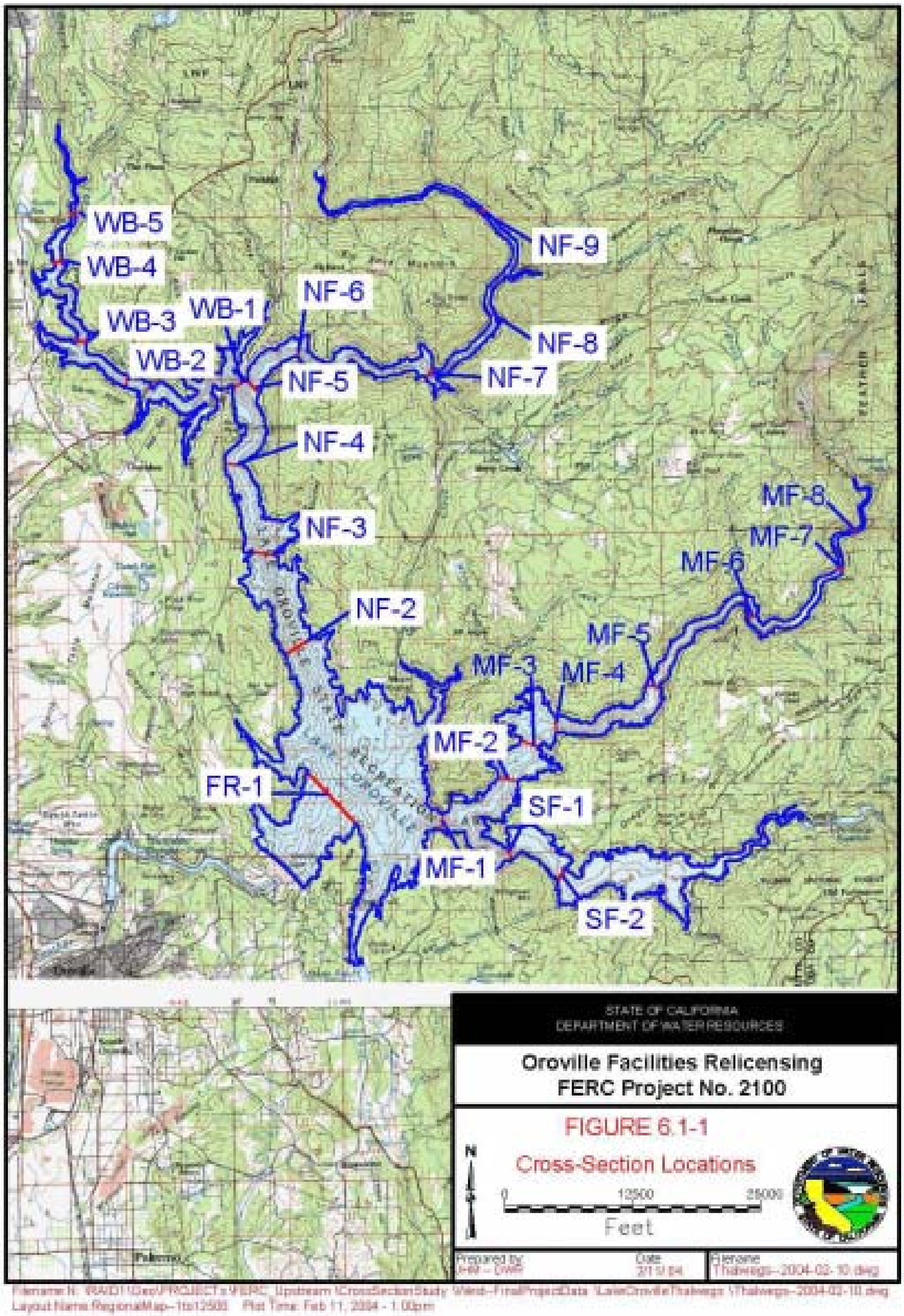


Figure 6.1-1. **Cross-Section Locations.**

6.1.2 Study Results

This section discusses the results of the re-survey for each section in greater detail. It includes approximations of sediment accumulation depths and volumes. Possible reasons for variations among the surveys from 1971 and 1993/94 and the original contour data are discussed where warranted.

6.1.2.1 WB-1

Cross-section WB-1 is located on the West Branch just upstream from the confluence with North Fork (Plates 6.1-3 and 6.1-27). All three survey data and the 1967 original contour data agree well except for a 20 to 30 feet shift right for the 1971 survey data and a 10 to 30 feet shift left for the 1994 survey data along the lower and middle portions of the right bank. Thalweg data from the 1993 and 2002 data indicate that approximately 9 feet of sediment has accumulated between the two surveys. Maximum thalweg sedimentation depth is approximately 21 feet. Total thalweg area sedimentation for WB-1 is about 1,000 square feet.

6.1.2.2 WB-2

Cross-section WB-2 is located on the West Branch approximately one mile upstream from the Highway 70 Bridge (Plates 6.1-4 and 6.1-28). The 1967 original contour data appear shifted 30 to 60 feet to the right over the entire cross-section. The 1971 survey data also appear shifted to the right along the upper right slope. This section was not surveyed during the 1993-94 sedimentation study. Maximum thalweg sedimentation depth is approximately 23 feet. Total thalweg area sedimentation for WB-2 is about 3,900 square feet.

6.1.2.3 WB-3

Cross-section WB-3 is located just upstream of the Lime Saddle Marina (Plates 6.1-5 and 6.1-29). The 1967 original contour data agree well with the 2003 survey data along both the side slopes and in the thalweg. The 1971 survey data appear shifted to the left 40 to 80 feet. Maximum thalweg sedimentation depth is approximately 17 feet. Total thalweg sedimentation area for WB-3 is about 1,200 square feet.

6.1.2.4 WB-4

Cross-section WB-4 is located about 0.67 miles downstream from the narrows at Cape Horn (Plates 6.1-6 and 6.1-30). The 1967 original contour data appear shifted toward either shore 25 to 50 feet. The 1971 survey data agree well with the 2003 survey data along both slopes. Thalweg data from the 1971 and 2003 data indicate that approximately 28 feet of sediment has accumulated between the two surveys. Total thalweg sedimentation area for WB-4 is about 2,500 square feet.

6.1.2.5 WB-5

Cross-section WB-4 is located about 0.33 miles upstream from the narrows at Cape Horn and about 0.5 miles downstream from the confluence with Concow Creek (Plates 6.1-7 and 6.1-31). Both the 1971 survey data and the 2003 survey data agree fairly well with the 1967 original contour data. This cross-section contained no significant sediment deposits at the time of the surveys. Photo 6.1-1 shows the West Branch thalweg just about 200 feet upstream of WB-5. The photo was taken in fall 2002, when the reservoir elevation was approximately 700 feet. The remnant sediment deposits along the left side of the river indicate that a large sediment deposit had previously occupied this section but has now moved further downstream.

6.1.2.6 FR-1

Cross-section FR-1 is located 1.2 miles upstream of Oroville Dam and crosses the thalwegs of both the North Fork and Middle Fork (Plates 6.1-8 and 6.1-32). The 1967 original contour data appear shifted toward either shore 25 to 50 feet. The 1971 survey data generally agree well with both the 1967 original contour data and the 2002 survey data except along the thalweg and lower portion of the right slope. It is possible that the boat was significantly off line while surveying the nearly 1.5 mile long cross-section. The 2002 survey data agree well with the 1967 original contour data. Maximum thalweg sedimentation depth is approximately 26 feet. Total thalweg sedimentation area for FR-1 is about 5,600 square feet.

6.1.2.7 NF-2

Cross-section NF-2 is located approximately 1.3 miles up the North Fork arm from the main basin (Plates 6.1-9 and 6.1-33). The 1971 survey data appear shifted approximately 50 feet to the left, particularly in the thalweg and lower slopes. The 1994 data and 2003 data agree closely. Thalweg sedimentation between 1994 and 2003 is approximately 10 feet. Thalweg elevation based on the original contours appears to be high; it is presumed that the original thalweg elevation was approximately 25 feet lower than shown. Maximum thalweg deposition depth is approximately 25 feet. Sedimentation along the lower portion of the left bank ranges from 10 to 25 feet; these values may be excessive based on possible inaccuracies in the 1967 original contour data. Total thalweg sedimentation area for NF-2 is about 11,000 square feet.

6.1.2.8 NF-3

Cross-section NF-3 is located approximately 3.3 miles up the North Fork arm from the main basin (Plates 6.1-10 and 6.1-34). The 1971 survey data is very poor with a shift of 50 to 100 feet to the right. The 1994 survey data along the right slope appear to be inaccurate. Elevation differences between the 1994 data and the 2003 data along flat spot on the lower left bank and in the thalweg correlate well. Total thalweg sedimentation depth is approximately 27 feet. Sedimentation along the lower portion of the left bank ranges from 7 to 20 feet; these values may be excessive based on possible inaccuracies with the 1967 original contour data. Total thalweg sedimentation area for NF-3 is about 8,400 square feet.

6.1.2.9 NF-4

Cross-section NF-4 is located approximately 1.8 miles down the North Fork arm from the confluence with the West Branch (Plates 6.1-11 and 6.1-35). The 1971 survey data correlates fairly well along the lower portion of the right bank; it probably also portrays the thalweg profile more accurately than the 1967 original contour data. The 1994 and 2003 survey data correlate well along upper portions of the side slopes. Maximum thalweg sedimentation depth is approximately 25 feet. Total thalweg sedimentation area for NF-4 is about 1,700 square feet.

6.1.2.10 NF-5

Cross-section NF-5 is located on the North Fork just upstream from the confluence with the West Branch (Plates 6.1-12 and 6.1-27). The 1967 original contour data appear to be shifted about 50 feet to the right, particularly in the thalweg and right slope. The 1971 survey data correlates well with the 2003 survey data. The 1994 data appear to show the elevations lower than expected. Some sedimentation appears to have occurred on the lower right slope and may be slough from the steep slope. Maximum thalweg sedimentation depth is approximately 37 feet. Total thalweg sedimentation area for NF-5 is about 7,700 square feet.

6.1.2.11 NF-6

Cross-section NF-6 is located on the North Fork upstream from the confluence with the West Branch approximately 6600 feet (Plates 6.1-13 and 6.1-28). The 1971 survey data appear to be shifted about 50 feet to the left along the right slope. Thalweg elevations derived from the 1967 original contour data appear to be high; this is probably due to no data points across the thalweg portion for about 400 feet. Maximum thalweg sedimentation depth is approximately 49 feet. Total thalweg sedimentation area for NF-6 is about 17,300 square feet.

6.1.2.12 NF-7

Cross-section NF-7 is located on the North Fork just downstream from the confluence with Berry Creek (Plates 6.1-14 and 6.1-37). The 1971 survey data agrees well with the 1967 original contour data along the right slope; it also probably portrays the original thalweg contours better than the 1967 original contour data. The 1971 survey data along the left slope appear shifted approximately 40 feet to the left. The 1994 survey data and the 2003 survey data correlate well with about 20 feet of sediment accumulated between the two surveys. Photos 6.1-2 and 6.1-3 are pictures of NF-7, taken in fall, 2002 when the reservoir elevation was at or below 700 feet. The massive sediment deposit occupying the left portion of the thalweg can be seen just downstream of the abandoned railroad tunnel. Maximum thalweg sedimentation depth is approximately 90 feet. Total thalweg sedimentation area for NF-7 is about 27,000 square feet.

6.1.2.13 NF-8

Cross-section NF-8 is located on the North Fork approximately 0.8 miles downstream from the confluence with French Creek (Plates 6.1-15 and 6.1-38). The 1967 original contour data appear shifted 10 to 25 feet to the left along the upper left slope. All three surveys agree closely along the left slope; some shift is apparent for the 1971 survey data along the right slope. The 1971 survey data and the 1994 survey data agree closely in the bottom portion of the thalweg. The 2002 survey data indicates that a substantial amount of sediment has been deposited in the thalweg since 1994 with about 49 feet of sediment accumulated between the two surveys. Maximum thalweg sedimentation depth is approximately 54 feet. Total thalweg sedimentation area for NF-8 is about 6,400 square feet.

6.1.2.14 NF-9

Cross-section NF-9 is located on the North Fork approximately 1.4 miles upstream from the confluence with French Creek (Plates 6.1-16 and 6.1-39). The 1967 original contour data are probably inaccurate along the left bank; visual inspection when this cross-section was exposed by low water indicated that the left bank was significantly steeper closer to the thalweg. All three surveys agree closely except for the 1971 survey data near the upper right slope. The 1971 survey data indicates that approximately 16 feet of sediment had accumulated in the initial 4 year period. The 1994 survey data indicates that approximately half of that sediment had been scoured out by 1994. The 1994 survey data and the 2002 survey data are very similar along the thalweg and lower right slope. The 2002 survey did not include measurements along the left slope because of difficult access; the left slope is very steep bare rock with no apparent erosion or sedimentation. Maximum thalweg sedimentation depth is approximately 10 feet. Total thalweg sedimentation for NF-8 is about 900 square feet. Elevation of the bottom of the thalweg is 755 feet and the cross-section is commonly exposed annually as the reservoir level fluctuates.

6.1.2.15 MF-1

Cross-section MF-1 is located on the Middle Fork approximately 100 feet upstream of the Bidwell Bar Suspension Bridge (Plates 6.1-17 and 6.1-40). The 1971 survey data appear shifted about 50 feet to the right along the lower slopes and thalweg. The 1993 survey data appear shifted 20 to 40 feet to the left over most of the cross-section. The 2002 survey data agree closely with the 1967 original contour data. Thalweg data from the 1994 and 2002 data indicate that approximately 10 feet of sediment has accumulated between the two surveys. A significant amount of sedimentation has been deposited along the lower right slope and is probably a result of sloughing from the steep right bank. Maximum thalweg sedimentation depth is approximately 25 feet. Total thalweg sedimentation area for MF-1 is about 3,800 square feet.

6.1.2.16 MF-2

Cross-section MF-2 is located on the Middle Fork approximately 1.7 miles upstream of the Bidwell Bar Suspension Bridge (Plates 6.1-18 and 6.1-41). The 1967 original contour data appear shifted about 50 to 60 feet to the left along the lower slope of the left bank; it appears to correlate well along the left slope. The 1971 survey data may have a moderate amount of error to both the right and left along the right slope. The 1993 survey data agrees well along most of the left bank but appears shifted about 50 feet to the right along the upper right slope. In addition, the 1994 survey data show two high spots on both sides of the lower slopes and are probably bathymetry data errors. The 2002 survey data agrees well along the right slope and thalweg but appears shifted 50 to 70 feet along the lower left slope; this is probably due to errors in the 1967 original contour data. Thalweg data from the 1994 and 2002 data indicate that approximately 8 feet of sediment has accumulated between the two. Maximum thalweg sedimentation depth is approximately 43 feet. Total thalweg sedimentation area for MF-2 is about 3,600 square feet.

6.1.2.17 MF-3

Cross-section MF-3 is located on the Middle Fork approximately 2.6 miles upstream of the Bidwell Bar Suspension Bridge (Plates 6.1-19 and 6.1-42). All three survey data agree well with each other and the 1967 original contour data, except for the 1971 survey data near the upper portion of the left slope. Thalweg data from the 1993 and 2002 data indicate that approximately 8 feet of sediment has accumulated between the two surveys. Maximum thalweg sedimentation depth is approximately 16 feet. Total thalweg sedimentation area for MF-3 is about 3,500 square feet.

6.1.2.18 MF-4

Cross-section MF-4 is located on the Middle Fork approximately 3.3 miles upstream of the Bidwell Bar Suspension Bridge (Plates 6.1-20 and 6.1-43). All three survey data agree well with each other and the 1967 original contour data, except for a shift to the right along the lower portion of the right slope with the 1967 original contour data, and a shift to the left along the upper portion of the right slope with the 1971 survey data. The 1994 and 2002 survey data agree very closely along the entire section. Thalweg data from the 1994 and 2002 data indicate that approximately 10 feet of sediment has accumulated between the two surveys. Maximum thalweg sedimentation depth is approximately 37 feet. Total thalweg sedimentation area for MF-4 is about 3,800 square feet.

6.1.2.19 MF-5

Cross-section MF-5 is located on the Middle Fork approximately 5.6 miles upstream of the Bidwell Bar Suspension Bridge (Plates 6.1-21 and 6.1-44). The 1967 original contour data and 1971 survey data agree well except for a 20 to 40 feet shift along the upper portion of the right bank. The 1993 survey data has a considerable amount of error along the side slopes; examination of the original field notes cannot indicate the reason for the error. The 2002 survey data shows a shift toward the right in the lower portion of the left bank; this may indicate side slope sedimentation but is most likely an indication of error in the 1967 original contour data and the 1971 survey data. Thalweg data from the 1993 and 2002 data indicate that approximately 9 feet of sediment has accumulated between the two surveys. Maximum thalweg sedimentation depth is approximately 44 feet. Total thalweg sedimentation area for MF-5 is about 4,100 square feet.

6.1.2.20 MF-6

Cross-section MF-6 is located on the Middle Fork approximately 8.5 miles upstream of the Bidwell Bar Suspension Bridge (Plates 6.1-22 and 6.1-45). All three survey data agree well with each other and the 1967 original contour data, except for a 20 to 40 feet shift to the right along the upper portion of the left slope with the 1971 survey data. Thalweg data from the 1993 and 2002 data indicate that approximately 9 feet of sediment has accumulated between the two surveys. Photo 6.1-4 is a picture of the Middle Fork taken in fall, 2002 about 200 feet upstream of MF-6, showing the extensive thalweg sedimentation. Reservoir elevation at the time of the photo was 690 feet. Maximum thalweg sedimentation depth is approximately 90 feet. Total thalweg sedimentation area for MF-6 is about 18,700 square feet.

6.1.2.21 MF-7

Cross-section MF-7 is located on the Middle Fork approximately 10.9 miles upstream of the Bidwell Bar Suspension Bridge and approximately 2.1 miles downstream of the lake head (Plates 6.1-23 and 6.1-46). All three survey data agree well with each other, but the 1967 original contour data appear shifted to the left about 50 feet on portions of the side slopes. The 1993 survey data indicate that the section had been flushed of sediment at that time. The 2002 survey data indicate that approximately 21 feet of sediment occupied the thalweg. Photo 6.1-5 is a picture MF-7 taken in fall 2002 after the reservoir elevation had dropped to 700 feet. The 21 feet of sediment that had occupied this section just several months earlier had now been flushed further downstream, leaving remnant lag deposits along the sides. Maximum thalweg sedimentation depth (at the time of the 2002 survey) was approximately 21 feet. Total thalweg sedimentation area for MF-7 was about 1,300 square feet.

6.1.2.22 MF-8

Cross-section MF-8 is located on the Middle Fork approximately 11.8 miles upstream of the Bidwell Bar Suspension Bridge and approximately 1.2 miles downstream of the lake head (Plates 6.1-24 and 6.1-47). The 1967 survey data and the 2003 survey data agree fairly well with the 1967 original contour data along the steep side slopes. The 1994 survey did not measure side slopes. It should also be noted that the 1994 survey did not locate the original endpoints from 1967 and the data is suspect (i.e., it may be off-line several hundred feet either upstream or downstream). The 1971 survey data indicate that approximately 20 feet of sediment had filled the thalweg. The 1994 survey data and the 2003 survey data indicate that little to no sedimentation occupy the thalweg. Photo 6.1-6 is a picture MF-8 taken in fall 2003 after the reservoir elevation had dropped below 800 feet, showing little to no sedimentation. The elevation of the bottom of the thalweg is 810 feet and the cross-section is commonly exposed annually as the reservoir level fluctuates. Because summer flows in Middle Fork are high enough to transport the sediment, it would not be expected that a significant amount of sediment would accumulate and remain at this cross-section.

6.1.2.23 SF-1

Cross-section SF-1 is located on the South Fork approximately 1.3 miles upstream of the confluence with the Middle Fork (Plates 6.1-25 and 6.1-48). The 1971 survey data appears to have 20 to 70 feet shift towards the center on both side slopes. The 2002 survey data appears to agree well with the 1967 original contour data. Maximum thalweg sedimentation depth is approximately 17 feet. Total thalweg sedimentation area for SF-1 is about 1,200 square feet.

6.1.2.24 SF-2

Cross-section SF-2 is located on the South Fork approximately 2.7 miles upstream of the confluence with the Middle Fork and approximately 3.2 miles downstream from the Enterprise Bridge (Plates 6.1-26 and 6.1-49). The 1971 survey data agrees well with the 1967 contour data except for a 20 to 50 feet shift to the left along the lower right slope. The 2002 survey data agrees fairly well the lower slopes but shifts slightly outward along both upper slopes. Maximum thalweg sedimentation depth is approximately 27 feet. Total thalweg sedimentation area for SF-1 is about 2,200 square feet.

6.1.3 Sediment Accumulation Rates

Table 6.1-2 contains the total thalweg deposition at each cross-section. Determining the total amount of thalweg deposition is closely dependent upon the accuracy of the 1967 contour data. The 1967 contour data did not show contour information below the river surface. At many of the cross-sections (for example NF-2 and NF-8), subsequent surveys measured a deeper thalweg elevation than the original 1967 contour data. While this could be interpreted as erosion of material in the thalweg, it is assumed that the discrepancy is due to the additional river depth that was not originally measured.

Table 6.1-2 also contains sediment accumulation rates at the cross-sections based on elevations interpreted from the 1967 contour data and the 2002/03 survey data. It also contains accumulation rates between the 1993/94 surveys and the 2002/03 surveys when available. Cross-sections that are located primarily within the Fluctuation Zone (i.e., lowest elevation of the cross-section is greater than 600 feet) are identified by the shaded areas.

Table 6.1-2. Cross-Section Deposition Areas and Accumulation Rates

		Accumulation Rates							
Cross section	**Thalweg Deposition (sq.ft.)**	**Start Year**	**Ending Year**	**Depth (ft.)**	**ft. / yr.**	**Start Year**	**Ending Year**	**Depth (ft.)**	**ft. / yr.**
WB-1	1,000	1967	2002	21	0.60	1993	2002	9	1.00
WB-2	3,900	1967	2002	23	0.66				
WB-3	1,200	1967	2003	17	0.47				
WB-4	2,500	1967	2003	28	0.78				
WB-5	0								
FR-1	5,600	1967	2002	26	0.74				
NF-2	11,000	1967	2002	25	0.71	1994	2002	10	1.25
NF-3	8,400	1967	2002	27	0.77	1994	2002	5	0.63
NF-4	1,700	1967	2002	25	0.71	1994	2002	13	1.63
NF-5	7,700	1967	2002	37	1.06	1994	2002	18	2.25
NF-6	17,300	1967	2002	49	1.40	1993	2002	14	1.56
NF-7	26,800	1967	2002	90	2.57	1993	2002	20	2.22
NF-8	6,400	1967	2002	54	1.54	1993	2002	49	5.44
NF-9	900	1967	2002	10	0.29	1993	2002	3	0.33
MF-1	3,800	1967	2002	25	0.71	1994	2002	10	1.25
MF-2	3,600	1967	2002	43	1.23	1994	2002	8	1.00
MF-3	3,500	1967	2002	16	0.46	1994	2002	8	1.00
MF-4	3,800	1967	2002	37	1.06	1994	2002	10	1.25
MF-5	4,100	1967	2002	44	1.26	1993	2002	9	1.00
MF-6	18,700	1967	2002	90	2.57	1993	2002	9	1.00
MF-7	1,300	1967	2002	21	0.60				
MF-8	0								
SF-1	1,200	1967	2002	17	0.49				
SF-2	2,200	1967	2002	27	0.77				

NOTE

** Shaded areas identify cross-section that are located primarily within the Fluctuation Zone.

Sediment accumulation rates for cross-sections that are not in the Fluctuation Zone range from about 0.47 feet/year to 2.25 feet/year. The average accumulation rate for these cross-sections is 0.82 feet/year based on data between 1967 and 2002/03, and 1.25 feet/year based on data between 1993/94 and 2002. It is unclear why there is an inconsistency between the long term (i.e., 1967 to 2002/03) and the relatively short-term (i.e., 1993/94 to 2002) averages. The long-term averages are based upon an assumed thalweg elevation from the original 1967 contour data, and the short-term averages are based on data from bathymetric surveys. A reasonable estimate of annual sedimentation at cross-sections that are not in the Fluctuation Zone would be from 1 to 1.25 feet per year.

As sediment accumulates in the thalwegs, the thalweg elevation rises, and sediment is deposited over a wider area. As a result, sediment accumulation rates would decrease because the same amount of sediment is deposited over a larger area.

Cross-sections located within the Fluctuation Zone exhibit a greater fluctuation in sedimentation rates ranging from 0.29 feet/year to 5.44 feet/year. These cross-sections are occasionally exposed to fluvial conditions due to low reservoir levels and experience episodes of erosion between sedimentation episodes. Further discussion of these cross-sections is in Section 6.2.

6.2 THALWEG INVESTIGATION

Reservoir sedimentation in water supply reservoirs subject to periodic drawdown is a dynamic process. Sediment deposited in the tributary arms during high water is subject to reworking and redeposition as the reservoir elevations fluctuate. Because cross-section locations are static, those locations may not always indicate the amount of sediment in storage as deposits move down the thalwegs. Therefore, the thalwegs of the four major tributaries were investigated for indications of sediment deposition not revealed by the cross-sections.

6.2.1 Methodology

Bathymetry of the thalwegs was measured along the four main tributaries from Oroville Dam to the upstream extent of the reservoir from a boat using the same equipment employed in surveying the cross-sections in June 2003. Approximately 286,000 feet (54.2 miles) of thalweg trace were measured while the boat traveled at 4 miles per hour. The location of the original thalweg was derived from the 1967 contour mapping. The boat and instrumentation were kept on track above the original thalweg trace using GPS equipment. Wind and wave action occasionally moved the boat off course; when the boat was more than 40 feet off track, those data points were generally removed from the data set by the surveyor during post-processing. The thalweg traces were generally measured only once (as opposed to the cross-sections where several passes were made). Anomalous high elevations (generally in the extreme upper portions of the tributaries) were due to boat tracking deviations from the original thalweg and along the channel side slopes (aka “side-sloping”). The anomalies were more common in the upper tributaries because of the narrow river channel width and steep side slopes, as opposed to lower portions in the reservoir where the channel was wider and a moderate amount of sediment had accumulated.

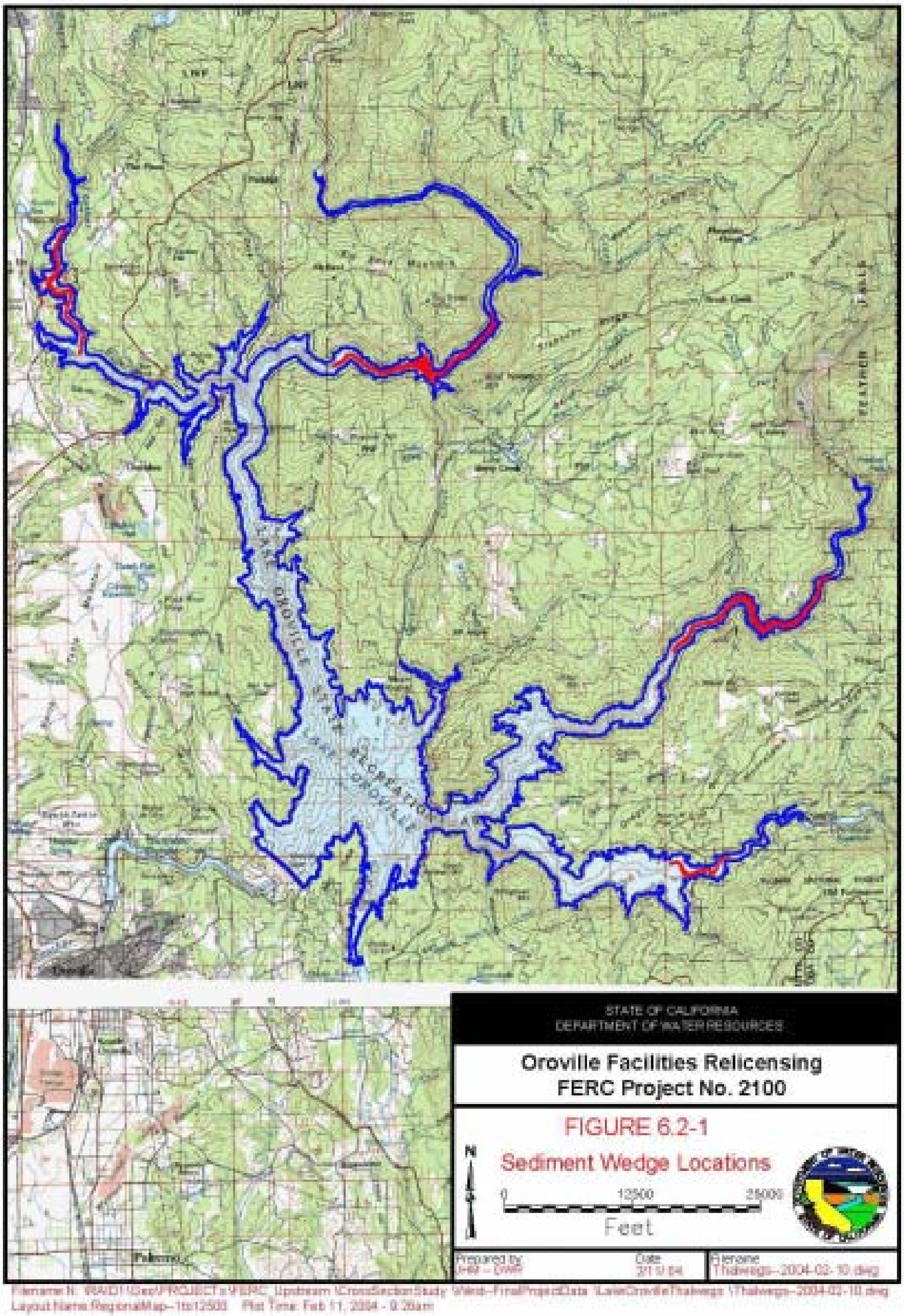


Figure 6.2-1. Sediment Wedge Locations.

6.2.2 Study Results

Thalweg trace depth measurements correlated well with cross-section depths where their locations intercepted, which served as a check on the bathymetry instrumentation. The thalweg bathymetry indicated substantial deposits of sediment in the middle upper portions of all four major tributaries (Figure 6.2-1). These deposits were located straddling the boundary between the Fluctuation Zone and the Reservoir Storage Zone.

6.2.2.1 West Branch Thalweg

Approximately 48,000 feet of the West Branch thalweg were sounded (Plates 6.2-1 and 6.2-2). The survey ended on the upstream portion when the channel became very narrow (less than 40 feet) and anomalous readings were prevalent. The first 8,500 feet of the thalweg had approximately 20 to 25 feet of sedimentation. The portions both downstream and upstream of Cross-section WB-2 appear to have minimal sedimentation; thalweg readings in this portion may be in error because the elevation "cross-check" with WB-2 has a fifteen foot discrepancy. A large sediment wedge begins slightly below WB-3 (elevation 570') and extends upstream to where the reservoir narrows downstream from Cape Horn (elevation 700'). The upper 5,000 feet of the wedge is nearly level with a 10 foot drop over the upper length (slope 0.002). The next 1,600 feet dip steeply dropping from 690 feet to 657 feet (slope 0.021). The wedge is nearly level for the next 2,200 feet dropping only four feet (elevation 653'). Another substantial drop in elevation occurs over the next 700 feet with the elevation dropping to 623 feet. The remaining 6,000 feet of sediment wedge slope moderately down to 570 feet elevation.

6.2.2.2 North Fork Thalweg

Approximately 109,000 feet of the North Fork thalweg were sounded (Plates 6.2-3 and 6.2-4). The survey ended on the upstream portion within sight of Big Bend Dam where the North Fork enters the reservoir (reservoir elevation at time of survey was approximately 860 feet). Thalweg sedimentation ranged from 10 to 25 feet along most of its length upstream to about Cross-section NF-4. At that point, the original thalweg slope increases and sedimentation decreases to 10 to 20 feet until the sediment wedge is encountered slightly upstream of Cross-section NF-6. The sediment wedge begins slightly upstream of NF-7 (elevation 709') and extends downstream about 20,000 feet to about the 530 foot elevation. The upper 11,200 feet of the wedge is nearly level with an 11 foot drop over the upper length (slope 0.001). The next 3,200 feet dip steeply dropping from 698 feet to 622 feet (slope 0.024). The slope moderates slightly over the remainder of the sediment wedge, dropping from 622 feet elevation to 539 feet over a 5,600 foot interval. Minor amounts of sediment are present above the sediment wedge up past Cross-section NF-9, but are generally less than five to ten feet deep. The high bathymetric readings both upstream and downstream of the French Creek confluence are probably due to "side-sloping" along the steep channel slopes. Photos 6.1-2 and 6.1-3 show a portion of the nearly level sediment wedge near the Berry Creek confluence.

6.2.2.3 Middle Fork Thalweg

Approximately 76,000 feet of the Middle Fork thalweg were sounded (Plates 6.2-5 and 6.2-5). The survey ended just upstream of Cross-section MF-8 (about 4,000 feet downstream of Frey Canyon) due to poor satellite reception for the GPS equipment. Thalweg sedimentation is minimal in the main basin (i.e., confluence with North Fork upstream to Bidwell Bar Bridge) gradually rising from about five feet to 25 feet. Sedimentation depth then varied from 25 to 45 feet up to the start of the sediment wedge. The sediment wedge starts about 1,000 feet downstream of MF-7 (elevation 718 feet) and extends downstream about 23,000 feet to about the 542 foot elevation. The upper 8,150 feet of the wedge is nearly level with a 7 foot drop over the upper length (slope 0.001). A moderately steep slope occurs over the next 500 feet with the elevation dropping 5 feet (slope 0.01) The next 6,350 feet dip gently dropping from 706 feet to 670 feet (slope 0.021). The sediment wedge then drops very steeply from 670 feet to 641 feet over a 200 foot interval (slope 0.145). The slope moderates slightly for a 4,300 foot interval dropping from 641 feet to 574 feet (slope 0.018). The slope is more gradual over the next 1,500 feet, dropping from 574 feet to 566 feet. The remaining 1,800 feet of sediment wedge drops slightly steeper ending at 542 foot elevation. No significant thalweg sediment deposits were detected upstream of the sediment wedge. Photos 6.2-3 and 6.2-4 show the downstream end of the upper nearly level portion of the sediment wedge entering Lake Oroville. The photos were taken in fall, 2002 when the reservoir level was at approximately 710 feet,

6.2.2.4 South Fork Thalweg

Approximately 76,000 feet of the South Fork thalweg were sounded (Plates 6.2-5 and 6.2-5). The survey ended on the upstream portion within sight of Ponderosa Dam where the South Fork enters the reservoir. Thalweg sedimentation varied from 10 to 20 feet along the lower portion, then appeared to decrease in the portion downstream from McCabe Creek. A small sediment wedge starts in the narrow river channel about 4,000 feet upstream from Enterprise Bridge and extends downstream about 7000 feet into the wider lake basin near McCabe Creek. The uppermost portion is very slightly inclined, dropping from 708 to 695 feet over 4,330 feet (slope 0.003). A fairly steep slope occurs over the next 560 feet with elevation dropping 18 feet to 670 feet. Another slightly gentle slope occurs over the next 1,000 feet, then a steep drop of 17 feet, and a final moderate slope. No significant thalweg sediment deposits were detected upstream of the sediment wedge.

6.2.3 Sediment Wedge Characteristics

The thalweg bathymetry indicated the presence of a substantial sediment wedge in all four major tributaries. Elevations of the upstream ends of the sediment wedges ranged from 700 to 720 feet at the time of the bathymetric survey. Elevations of the downstream ends ranged from 530 to 630 feet. All four sediment wedges had a long nearly level upper portion that ranged from about 4,300 to 11,200 feet in length. All sediment wedge profiles displayed a series of slope breaks downstream of the upper nearly level portion. Low reservoir levels in fall, 2002 exposed the upper portions of all four sediment wedges and were investigated by DWR staff.

6.2.3.1 West Branch Sediment Wedge

DWR staff investigated the West Branch sediment wedge in October 2002 when the reservoir level was at about 702 feet. Stream flow in the West Branch was estimated at about 20 cfs. At the time of the field visit, the upper nearly level portion was about ten to fifteen above the reservoir elevation. Photo 6.2-1 shows a portion of the sediment wedge at Slope Break “A”, showing the abrupt drop in elevation and delta formation at the lake level. Photo 6.2.-2 shows the river channel cutting into the upper portion of the sediment wedge. At the time of visiting the sediment wedge, the discharge volume of the West Branch was insufficient to continue eroding the upper portion of the sediment wedge down to the current reservoir elevation. As a result, the West Branch becomes slightly entrenched into the sediment as it passes over the upper portion of the wedge (Photo 6.2-3 and 6.2-4). Stream widths and depth across the wedge material vary from 5 to 20 feet and from 3 inches to 9 inches, respectively. Stream bed material is predominantly medium to fine sand with some gravel up to small cobble-size. The upper surface of the wedge is covered in fine silt outside of the entrenched stream channel.

6.2.3.2 North Fork Sediment Wedge

DWR staff investigated the North Fork sediment wedge in October and early December 2002. Reservoir levels continued to drop from 712 to 690 feet between the two visits. Stream flow in the North Fork during the October visit was fairly high and estimated at about 2,000 cfs (Photo 6.2-5). Stream flows further upstream occupied the entire channel and barred further safe access upstream of Berry Creek. Discharge volumes in the North Fork were sufficient enough to continue eroding the sediment material down to the lake/river interface. Stream widths across the upper portion of the sediment wedge vary but range from 150 to 250 feet. Safety issues prevented stream depth measurements; depths were estimated to range from about 2 to 6 feet. Stream turbidity was extremely high due to the constant erosion of the wedge material. Some channel downcutting of the wedge material occurs as the North Fork channel widens. Photo 6.2-6 shows a residual layer of the sediment wedge material that was not eroded as the North Fork flowed into the wider portion of the canyon at the Berry Creek confluence.

6.2.3.2 Middle Fork Sediment Wedge

DWR staff investigated the Middle Fork sediment wedge in late October 2002 when the reservoir level was at about 709 feet, and in early December when reservoir level was about 690 feet. Stream flow in the Middle Fork was fairly low and estimated at about 55 cfs (Photo 6.2-7). The upper portion of the sediment wedge was encountered about 1,500 feet upstream of Cross-section MF-6. During the early December 2002 visit, the sediment wedge was encountered about 200 hundred feet upstream of Cross-Section MF-6 (Photo 6.1-4). Photo 6.2-8 shows the same general location as Photo 6.2-6 (note orange-colored slope on right bank). As the water dropped 19 feet between the two visits, the Middle Fork had sufficient discharge volume so that nearly all of the wedge material was eroded down to the current lake elevation.

The Middle Fork exhibited a braided stream pattern across the wedge material with widths varying from 100 to 300 feet (Photo 6.2-9). Stream depths were estimated to range from 3 inches to 12 inches. The stream bed and bank material was predominantly fine to coarse-grained sand with rare fine to medium pebbles (Photo 6.2-10). Minor thin layers (up to one inch thick) of organic detritus (such as leave and twig litter) was occasionally found. Sediment material adjacent to the stream channel is water-saturated and occasionally exhibits a “quick-sand” nature when walked upon.

6.2.3.2 South Fork Sediment Wedge

DWR staff investigated the Middle Fork sediment wedge in early December 2002 when reservoir level was about 690. The upper portion of the sediment wedge was encountered about 200 feet downstream of Enterprise Bridge (Photo 6.2-11). Stream flow in the South Fork was very low and estimated at about 20 cfs. The South Fork exhibited a braided stream pattern across the majority of wedge material with widths varying from 50 to 125 feet (Photo 6.2-12). Stream depths were estimated to range from 2 inches to 8 inches. The stream bed and bank material was predominantly medium to coarse-grained sand with rare fine to medium pebbles. The bathymetry survey performed in spring 2003 indicated that the wedge material extended upstream about 2,000 feet but it was not visited in the field.

6.2.3 Sediment Wedge Movement

The movement of sediment wedge material is dependent upon several key criteria:

- Reservoir water level elevation
- Sediment wedge elevation
- Tributary discharge quantity
- Incoming sediment volume

If the reservoir elevation is greater than the uppermost elevation of wedge, lentic conditions predominate and the wedge material does not move appreciably. If the reservoir elevation is lower than the wedge material, fluvial conditions predominate and wedge material is transported further downstream by typical stream processes.

During the time of the field investigation, the uppermost elevations of the four sediment wedges ranged between 700 and 720 feet; reservoir elevations ranged between 712 and 690 feet. Fluvial processes predominated and upper portions of the sediment wedges were actively being eroded and carried down to lake level elevations. This phenomena was best displayed on the Middle Fork upstream of Cross-section MF-6 (Photos 6.2-7 and 6.2-8): reservoir elevations dropped about 19 feet during the two field visits and the slope break at the downstream end of the upper portion (i.e., Slope Break "A") migrated 1,300 feet downstream, essentially keeping pace with receding lake level elevations.

The movement of material on the upper portions of the sediment wedges is also well represented in the thalweg elevations at Cross-section NF-8 (Plates 6.1-15 and 6.2.4). The channel profile at NF-8 was surveyed in late July 2002 when reservoir elevations were about 775 feet; the thalweg elevation was about 725 feet. During the winter of 2002/03, the reservoir elevation dropped as low as 690 feet, and fluvial processes (i.e., erosion of the wedge material) predominated. By June 2003, reservoir elevations approached full pool level (900 feet), and the North Fork thalweg was surveyed. Thalweg elevation at NF-8 was surveyed at 700 feet, indicating that 20 feet of thalweg sediment had eroded between July 2002 and June 2003.

As tributary discharge increases and reservoir elevations rise closer to the elevation of the upstream end of a sediment wedge, increasing amounts of sediment are eroded. Figures 6.2-2 and 6.2-3 show the Lake Oroville elevation and Merrimac gage discharge quantity. The Merrimac gage is located on the Middle Fork about 10 miles upstream from Lake Oroville. A large storm event in mid-December, 2002 resulted in Lake Oroville rising 20 feet over a four day period. Flow volumes in the Middle Fork increased from under 1,000 cfs to nearly 7,000 cfs then dropped down to below 2,000 cfs before peaking at 7,600 cfs in late December. The higher flows and higher lake elevations transported additional wedge material from the upper portion of the wedge, downstream to the 710 foot elevation where Slope Break "A" (Plate 6.2-6) is found. Over the next ten days, the reservoir level gradually rose from 710 feet to 720 feet, at which time all portions of the sediment wedge were inundated and no longer subject to fluvial processes promoting downstream migration of sediment. During 2002, the Middle Fork sediment wedge material was exposed to erosion only for a period of about 90 days, from late September to late December. Sediment wedges on the other three tributaries experienced similar short exposures of erosion during 2002.

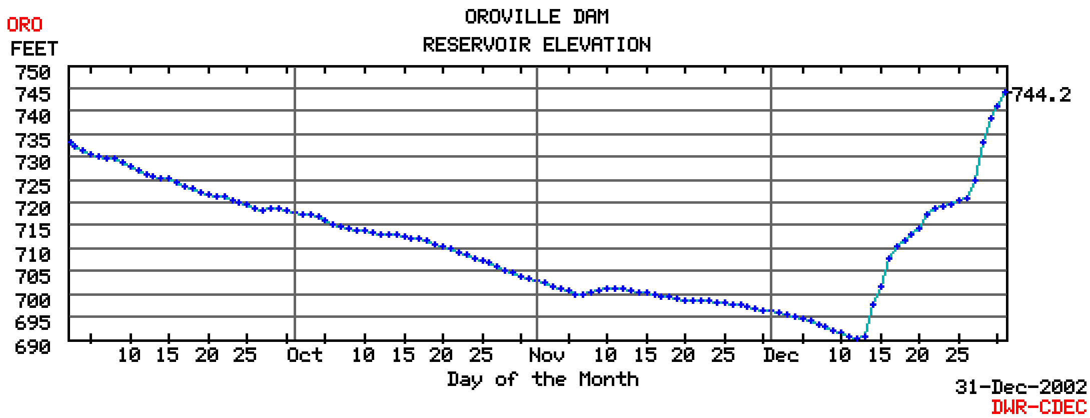


Figure 6.2-2. Lake Oroville elevations, September through December, 2002.

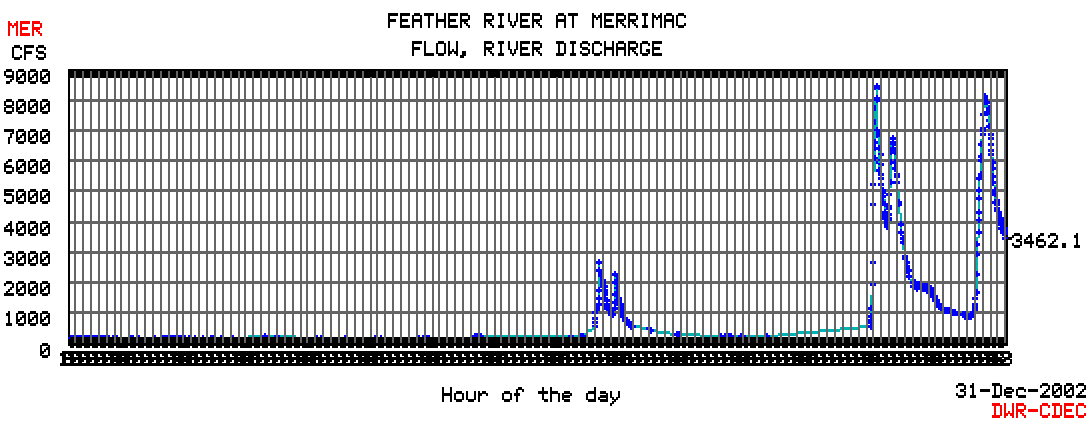


Figure 6.2-3. Middle Fork discharge, September through December, 2002.

If reservoir levels exceed the elevation of the sediment wedges, material is not transported further downstream. For example, during 2003, Lake Oroville filled to capacity (900 foot elevation) then dropped to 787 feet by early December, and began rising again. All sediment wedge material was covered by at least 60 feet of lake water; fluvial processes did not affect the wedge material and it is assumed that the wedge material did not move appreciably.

The January 1997 storm event in the Feather River watershed introduced significant amounts of sediment into Lake Oroville. Reservoir elevation rose dramatically from around 840 feet to nearly 890 feet over a five day period, and then gradually dropped back to the 840 foot range within two weeks (Figure 6.2-4). The bulk of the sediment entered Lake Oroville when reservoir elevations were close to full pool level (900 feet); large volumes of sediment were deposited in the extreme upper portions of the lake arms. Photo 6.3-12 shows a large accumulation of sediment in the North Fork arm just upstream of French Creek in August, 1997. Field investigations during 2002 and 2003 indicated that the 1997 sediment deposit has been reworked by fluvial processes since 1997 and has been deposited further downstream.

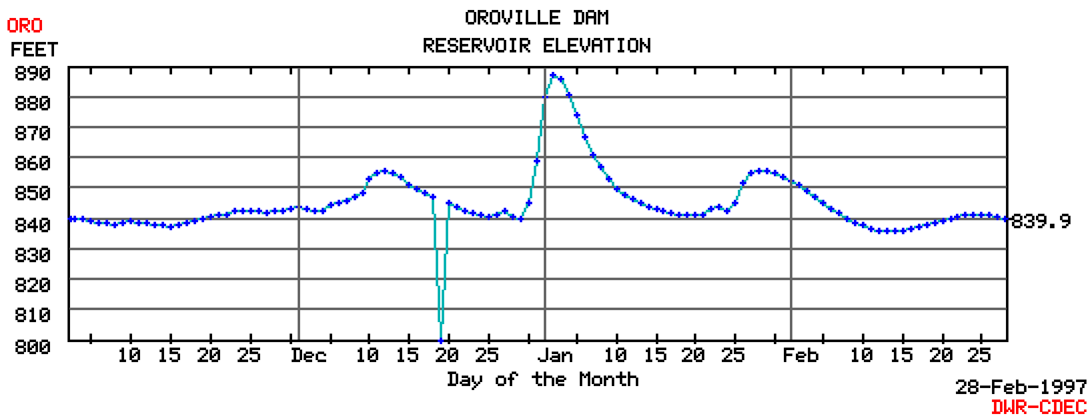


Figure 6.2-4. Lake Oroville elevations, November through February 1997.

Since the January 1997 storm event, Lake Oroville reservoir elevations have fluctuated between 690 feet and maximum pool level (900 feet) (Figure 6.2-5). Annual low water elevations dropped successively from 1998 to 2002 from 840 feet to 690 feet. As a result, nearly all of the sediment material from the 1997 storm event has been transported to below the 720 foot elevation.

Three of the four sediment wedges have nearly level portions towards the downstream ends between around the 610 to 675 foot elevations (Table 6.2-1). These portions are best portrayed on the West Branch thalweg (Plate 6.2.2), which has a 2,200 foot interval dropping only 4 feet from 657 feet to 653 feet. The historic low reservoir elevations of 645 feet (September 1977) and 651 feet (January 1991) likely caused the wedge material higher up to erode down to the reservoir base levels at those times. This indication of "lowest base level" is obscured in the North Fork because incoming sediment material since the low water events has already coalesced over the existing sediment wedge material located in this elevation interval.

The downstream ends of the sediment wedges range in elevation from 530 to 629 feet. Deposition of wedge material at these lower elevations occurs primarily when the reservoir levels are near their lowest levels. Because the reservoir level has not been lower than 645 feet, wedge material is not deposited substantially deeper than about 100 feet below that elevation. It is likely that the sediment wedge will continue to grow at the 500 to 700 foot level rather than continuing to migrate downstream to lower elevations.

Table 6.2-1. Sediment Wedge Slope Characteristics

West Branch	Elev (ft.)	Interval Length (ft.)	Slope
Wedge Top	700		
		5,375	-0.002
Slope Break "D"	690		
		1,610	-0.020
Slope Break "C"	657		
		2,165	-0.002
Slope Break B"	653		
		725	-0.041
Slope Break "A"	623		
		5,925	-0.009
Wedge Bottom	570		

North Fork	Elev (ft.)	Interval Length (ft.)	Slope
Wedge Top	720		
		11,210	-0.002
Slope Break "B"	698		
		3,325	-0.023
Slope Break "A"	622		
		5,575	-0.017
Wedge Bottom	530		

Middle Fork	Elev (ft.)	Interval Length (ft.)	Slope
Wedge Top	718		
		8,150	-0.001
Slope Break "F"	711		
		500	-0.010
Slope Break "E"	706		
		6,350	-0.006
Slope Break "D"	670		
		200	-0.145
Slope Break "C"	641		
		4,300	-0.016
Slope Break "B"	574		
		1,525	-0.005
Slope Break "A"	566		
		1,800	-0.013
Wedge Bottom	542		

South Fork	Elev (ft.)	Interval Length (ft.)	Slope
Wedge Top	708		
		4,330	-0.003
Slope Break "D"	695		
		560	-0.032
Slope Break "C"	677		
		1,010	-0.009
Slope Break "B"	668		
		170	-0.100
Slope Break "A"	651		
		890	-0.025
Wedge Bottom	629		

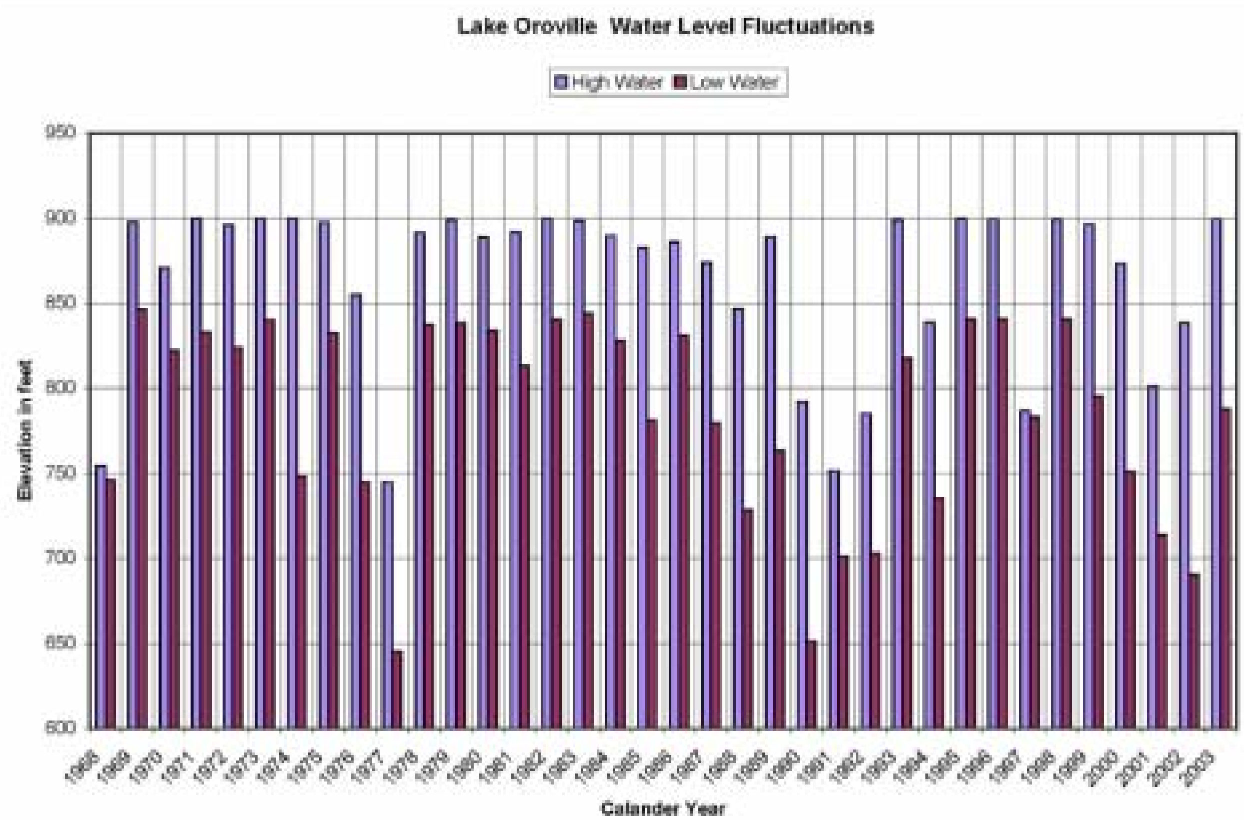


Figure 6.2-5. Lake Oroville Water Level Fluctuations.

6.2.4 Remnant Wedge Material Within the Fluctuation Zone

Although the greater bulk of sediment currently resides below the 720 foot elevation, some minor sediment features still reside above 720 feet within the fluctuation zone. Lateral gravel and sand deposits along the edges of the exposed river channel were observed in the West Branch Middle Fork, and South Fork (Photos 6.2-14 through 6.2-16). These deposits (a.k.a. lag deposits) are remnant portions of the sediment wedge material when the sediment wedge resided further up within the fluctuation zone. The lag deposits are generally located in the wider portions of the former river channel where the stream energy tended to erode only the center portion of the channel. The sediment characteristics are similar to materials in the sediment wedge, but have a greater amount of cobble-size material.

6.3 SLOPE STABILITY INVESTIGATION

Slope stability depends upon the equilibrium between forces acting to resist slope failure and forces acting to cause it. Resistant forces include the inherent bedrock and soil strength, cohesion, and vegetative cover. Active forces that reduce slope stability include the natural slope of the area and increased slope caused by stream or lakeshore erosion. ground water conditions, planes of internal weaknesses, localized weight increase such as road fills or soil saturation during storms, and loss of vegetative cover.

Common types of slope instability features include landslides (both translational and rotational), earthflows, and debris slides (Varnes, 1958). The distinction between different types of landslides is often gradational. Seasonal variations in the amount of moisture contained in a landslide mass can affect the type of movement. Translational slides become earthflows as moisture content increases. Earthflows may merge into debris slides as slopes steepen and soil cover thins. For the purposes of this report, all types of slope instability features are broadly referred to as landslides.

6.3.1 Methodology

An initial assessment of possible areas of slope instability was performed by producing a slope map from the USGS Digital Elevation Model (DEM) data files (Figure 6.3-1). Areas of slope instability were then mapped using aerial photography and confirmed in the field. Field confirmation included boating to each slide looking for scarps, rubble and debris lobes at the base (low lake levels made this possible), any other signs of movement, and walking the boundaries if necessary. Some of the landslide locations were derived from previously completed DWR landslide maps. Appendix C contains map coverage of landslides around Lake Oroville.

The type of motion on each landslide was determined and then classified as ancient, active or inactive (DWR, 1982).

A debris slide is unconsolidated rock, colluvium, and soil that has moved downslope along a relatively shallow failure plane. Debris slides form steep unvegetated scars in the head region and irregular hummocky deposits in the toe region. A rock chute is an extreme variety of debris slide, typically occurring on near-vertical barren slopes or drainages (Photo 6.3-1) A translational – rotational slide is characterized by a cohesive slide mass and a failure plane that is deeper that a debris slide. The motion is linear for the translational portion and arcuate in the rotational portion. Generally these slides have rotational heads and translational bodies. An earthflow is mass movement resulting from flow of saturated soil and debris in a semi-viscous, highly plastic state.

Active landslides display evidence of recent movement, such as fresh barren scarps, jackstrawed trees (Photo 6.3-2), displaced roads and stream channels, and clusters of large rocks in stream channels or lake shore. Vegetation on active landslides is typically sparse, with willow, grass, and brush predominant.

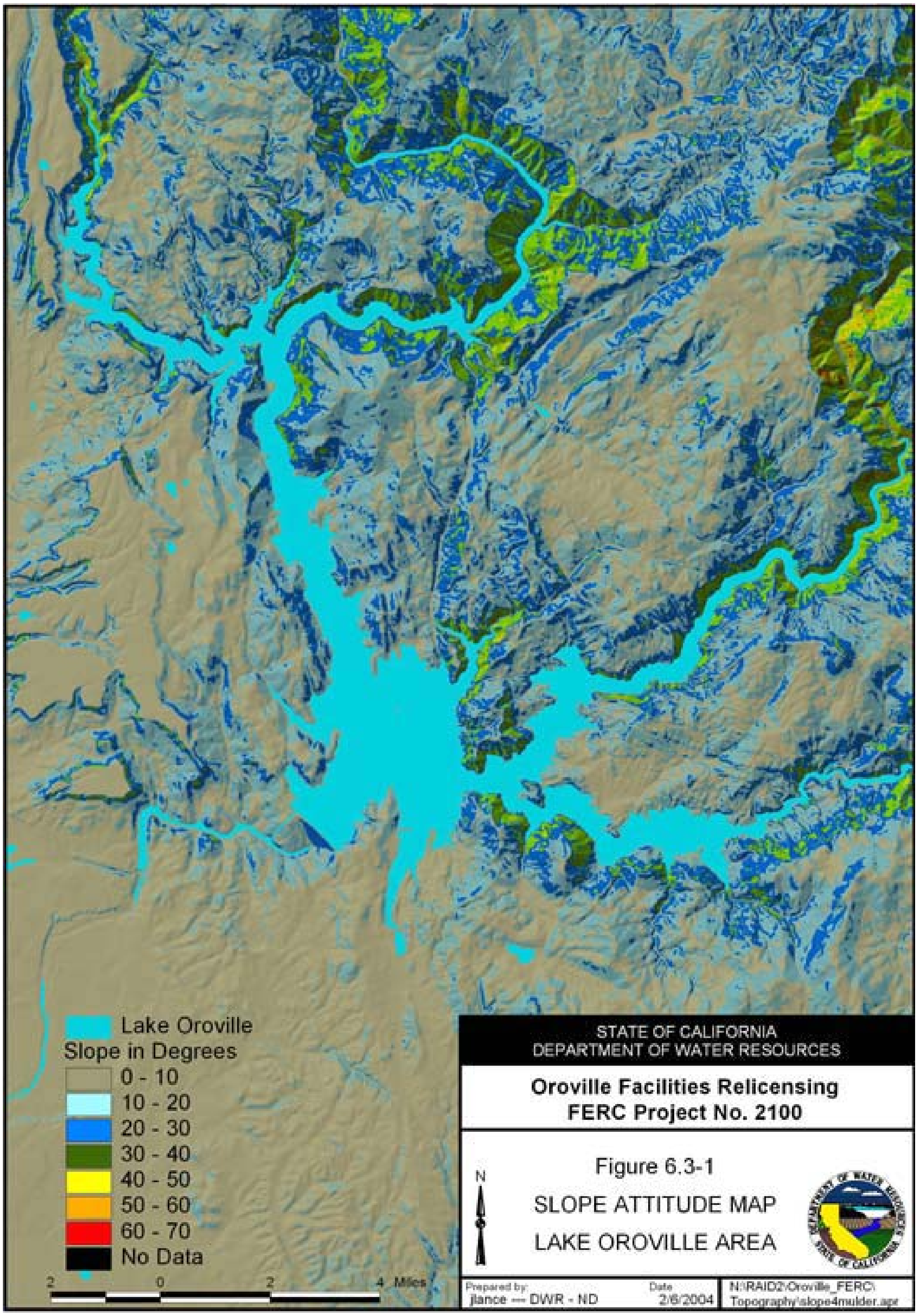


Figure 6.3-1. Slope Attitude Map – Lake Oroville Area.

Inactive landslides have well-developed and easily recognized slide topography. Bowl- or spoon-shaped depressed areas are bounded by steep crown and flanking slopes. Flat lobes and irregular hummocky topography are well defined. Depressed sags and ponds, water seeps, and water-loving vegetation are common. Vegetation is generally a well-established, mature forest stand but may vary in type and density from surrounding stable areas. Trees with bowed trunks occur. This feature may indicate that deep-seated movement is presently occurring at slow rates. Inactive landslides define areas of past instability and indicate sensitivity to erosion and mass wasting.

Ancient landslides have indistinct boundaries and subdued landslide form. Crown and flanking slopes are rounded and ill-defined. Sags and ponds are typically absent. These landslides usually are covered by well-established, mature stands of the same age class as the surrounding forest. The lack of well-defined features and boundaries suggests that many hundreds—perhaps thousands—of years have passed since active movement occurred. Ancient landslides outline zones where deep soil and disturbed rock can be expected to be sensitive to management projects. Roads that cross both inactive and ancient landslide areas commonly have cut-and-fill slope failure problems associated with clay soils and high water tables.

6.3.2 Study Results

Numerous landslides exist along the banks of Lake Oroville. The landslides occur in granitic and metamorphic rocks that form the hills and valleys of the westernmost portion of the Sierra Nevada. Many of the landslides continue into the depths of the reservoir. It is common for the motion to occur along joint and/or fracture planes, especially in the granitic rocks.

The area of all the confirmed landslides mapped in the Lake Oroville area is approximately 4154 acres. Of that, 328 acres (8%) are active, 579 acres (14%) are inactive, and the remaining 3246 acres (78%) are ancient landslides (Table 6.3-1 and Figure 6.3-2). Approximately 75,000 feet of shoreline is mapped as landslide material. Based on a total shoreline length of 980,000 feet, less than 8% is considered landslide material.

Table 6.3-1. Landslide Acreage and Activity Status

Activity Status	Total Acreage	Percent
Active	328	8%
Inactive	579	14%
Ancient	3,246	78%
Totals	4,154	100%

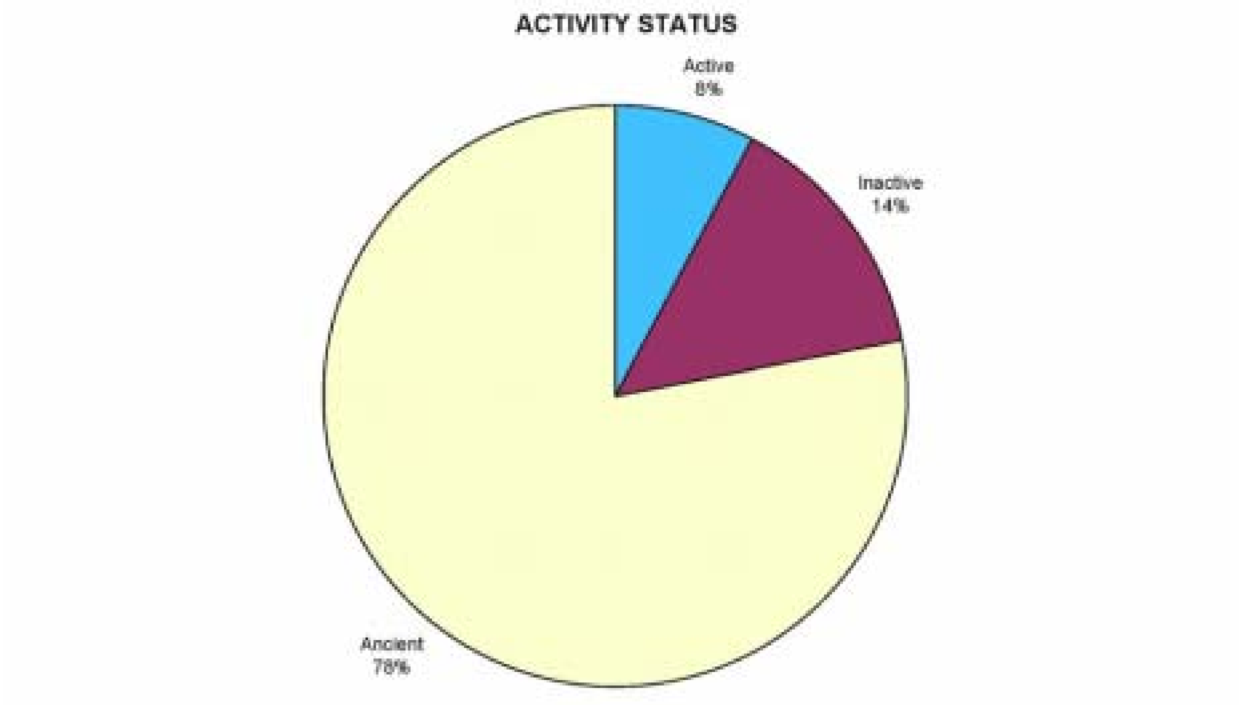


Figure 6.3-2. Landslide Activity Status.

The majority of the active landslides are a result of reactivation of inactive or ancient landslides. There are also a substantial number of small active landslides that are due to bank/toe failure at the edge of the reservoir, particularly on the Middle Fork (Photos 6.3-3 and 6.3-4). These are likely caused by the repeated wave action along the shoreline under cutting already unstable areas. The largest inactive landslide in the study area is the Bloomer Hill landslide, along the southern shore of the upper North Fork downstream from Berry Creek. Isolated portions of the Bloomer Hill landslide have reactivated likely from saturation of the slide mass (Photo 6.3-5).

The Stringtown Mountain Landslide, located on the south shore of the lower South Fork, is an example of reactivation of a portion of an ancient landslide (Photo 6.3-6). The center portion has reactivated, but the date of reactivation is unknown. Discussions with Oroville Field Division staff (pers. Comm., August, 2004) indicated that the slide occurred soon after the initial filling of Lake Oroville. No documentation of the slide reactivation was found in DWR files.

Nearly half (46%) of the total landslide area is derived from the arc complex rocks (Table 6.3-2 and Figure 6.3-3), with the other rock types containing a range of 13% to 26% of the landslide area. The ancient Bloomer Hill landslide accounts for over 1,500 acres of the total landslide area of 4,154 acres, and located predominantly in the arc complex rocks.

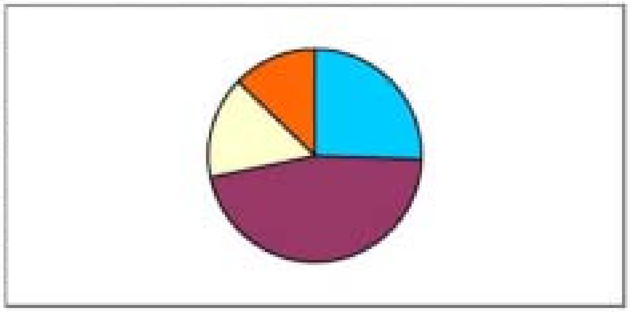
The majority (66%) of the active landslide area is located on mélange-derived rocks, primarily along the steep shorelines of the upper North Fork. Intrusive rocks along the Middle and South Forks account for 24% of the active landslide area. The remaining 9% occurs in the arc complex rocks (Figure 6.3-3).

The amount of material derived from active landslide activity is considered minimal when compared to the amount of incoming watershed erosion sediment and shoreline erosion sediment. Nonetheless, it should be noted that significant reactivation of the inactive or ancient slide masses (such as the ancient Bloomer Hill Landslide) could introduce extremely large volumes of material into the reservoir and could even block portions of the upper arms Lake Oroville

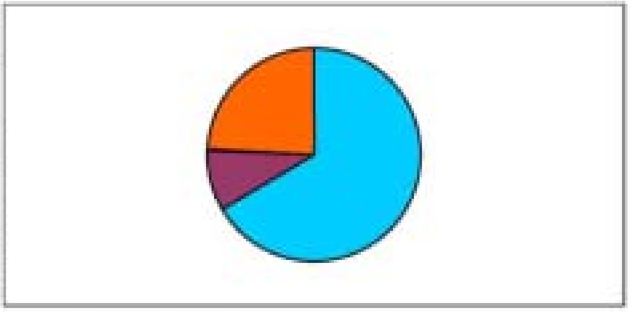
Table 6.3-2. Total Landslide Areas Sorted by Rock Type and Activity Status.

Figure 6.3-3 Total Landslide Areas Sorted by Rock Type & Activity Status

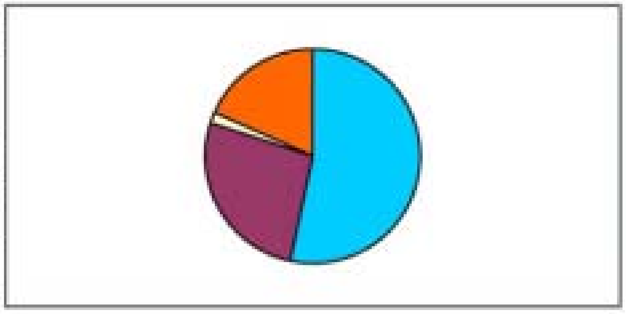
Rock Type	Total Landslides	
	Total Acreage	Percent
Melange	1066	26%
Arc Complex	1913	46%
Smartville ophiolite	640	15%
Intrusive	535	13%
Totals	4154	100%



Rock Type	Active Landslides	
	Total Acreage	Percent
Melange	218	66%
Arc Complex	30	9%
Smartville ophiolite	1	0%
Intrusive	79	24%
Total	328	100%



Rock Type	Inactive Landslides	
	Total Acreage	Percent
Melange	308	53%
Arc Complex	154	27%
Smartville ophiolite	9	2%
Intrusive	107	18%
Total	579	100%



Rock Type	Ancient Landslides	
	Total Acreage	Percent
Melange	539	17%
Arc Complex	1729	53%
Smartville ophiolite	629	19%
Intrusive	349	11%
Total	3246	100%

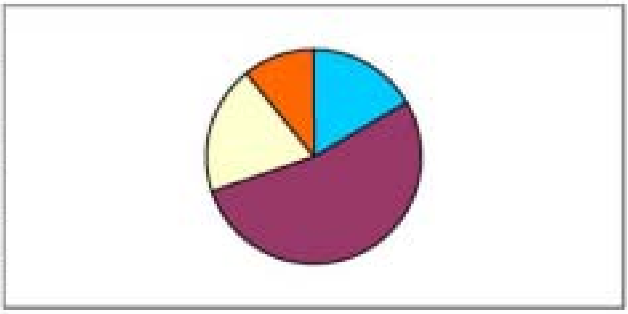


Figure 6.3-3 Total Landslide Areas Sorted by Rock Type & Activity Status

6.4 SHORELINE EROSION INVESTIGATION

Reservoirs typically have extremely elongated shorelines compared to natural lakes (Morris and Fan, 1997). Lake Oroville has a shoreline perimeter of approximately 980,000 feet (186 miles) when the reservoir is at full pool level and its surface area is approximately 668,766,000 square feet (15,352 acres). The shoreline perimeter decreases to approximately 563,000 feet (107 miles) when the reservoir elevation is at 640 feet and its surface area is approximately 252,473,000 square feet (5,796 acres). The areal extent between the shoreline at full pool level and the shoreline at 640 feet (i.e., areal extent of the Fluctuation Zone) is approximately 416,294,000 square feet (9,557 acres).

Shoreline erosion and slope failures are most prevalent during the first months or years of initial impoundment (Morris and Fan, 1997). The amount of bank erosion for a particular length of shoreline is closely related to the underlying geologic material and soil cover. In addition, shorelines fronting on a large lake expanse may have more erosion due to increased wave/wind action, whereas wind-protected coves off of the main portions of the lake have less erosion due to the decreased wave/wind action.

6.4.1 Methodology

Bank erosion was surveyed in spring 2003 when the reservoir was within 20 feet of full pool elevation. The bank erosion was rated as the amount of vertical bank created (i.e., escarpment) at the full pool level elevation on a 4-point scale from 0 to 3:

- 0 No erosion to less than 0.5’
- 1 0.5’ to 2.0 feet
- 2 2.0 feet to 5.0 feet
- 3 5.0 feet or greater

The extent of shoreline precluded detailed surveying of its entirety. As an alternative, selected spots (usually at or near cross-section endpoints) were measured with a stadia rod and the adjacent shorelines were visually accessed from a boat. Numerous dead tree stumps are within the Fluctuation Zone (Photos 6.4-1 and 6.4-2) and many were evaluated for the amount of soil erosion since the initial filling of the reservoir. Appendix C presents the bank erosion mapping in addition to the landslide mapping.

6.4.2 Study Results

Photo 6.4-3 shows a typical bank along the lower portion of the North Fork, where approximately five feet of soil has been eroded away producing a near-vertical escarpment. The landward extent of erosion is generally minimal because the bank slopes are underlain by resistant bedrock. As the overlying soil is eroded away, more resistant bedrock hampers additional landward erosion.

Steeply sloping soil-covered banks generally exhibit a higher bank erosion escarpment and occasionally merge into active debris slide locations (Photo 6.4-4). There is a high degree of correlation between extensive bank erosion and landslide/debris slide locations. Steeply sloping barren banks, commonly located in the upper rocky portion of the tributary arms, exhibit a low amount of bank erosion due to the absence of overlying soil cover (Photo 6.4-5).

Moderately sloping banks, most prevalent in the main basin and lower portions of the tributary arms, exhibit a range of erosion levels. In general, these areas are more susceptible to wave action from wind currents across a wide expanse of water, and from wave action due to recreational boating.

Gently sloping banks are rare along the shoreline. Bank erosion on gently sloping banks where wave/wind action is prevalent can be high because more landward slope can be eroded until resistant bedrock is exposed. Gently sloping banks in secluded coves such as those west of the Lime Saddle Marina and Potter's Ravine exhibit minimal erosion due to protection from wave/wind action and slower recreational boating speeds.

The underlying geologic material is a major factor in the development of the soil profile. The metamorphic and ophiolitic rocks underlying the central and western portions of the reservoir tend to develop a deeper soil profile as compared to the intrusive igneous rocks underlying the eastern portion. Intrusive rocks along the lower portions of the Middle and South Fork, however, decompose readily into their basic mineral assemblages. These decomposing granites do not generate a deep soil profile, but are readily eroded by wave/wind action.

Lower elevations in the Fluctuation Zone are exposed to erosion less frequently then those areas near the maximum pool level (900 feet). The lowest 100 feet of the Fluctuation Zone (i.e., from 640 feet to 740 feet) were exposed to shoreline erosion only 10 percent of the time between 1968 and 2003 (Figure 6.4-1). Areas above the 840 foot elevation were exposed to shoreline erosion over 60% of the time. Figure 6.4-1 also indicates that the shoreline elevation stayed within the relatively narrow range of 835 feet and 855 feet nearly 35% of the time; it is possible that bank erosion may be greater in this narrow elevation range due to the greater amount of time that wave action worked against the shore.

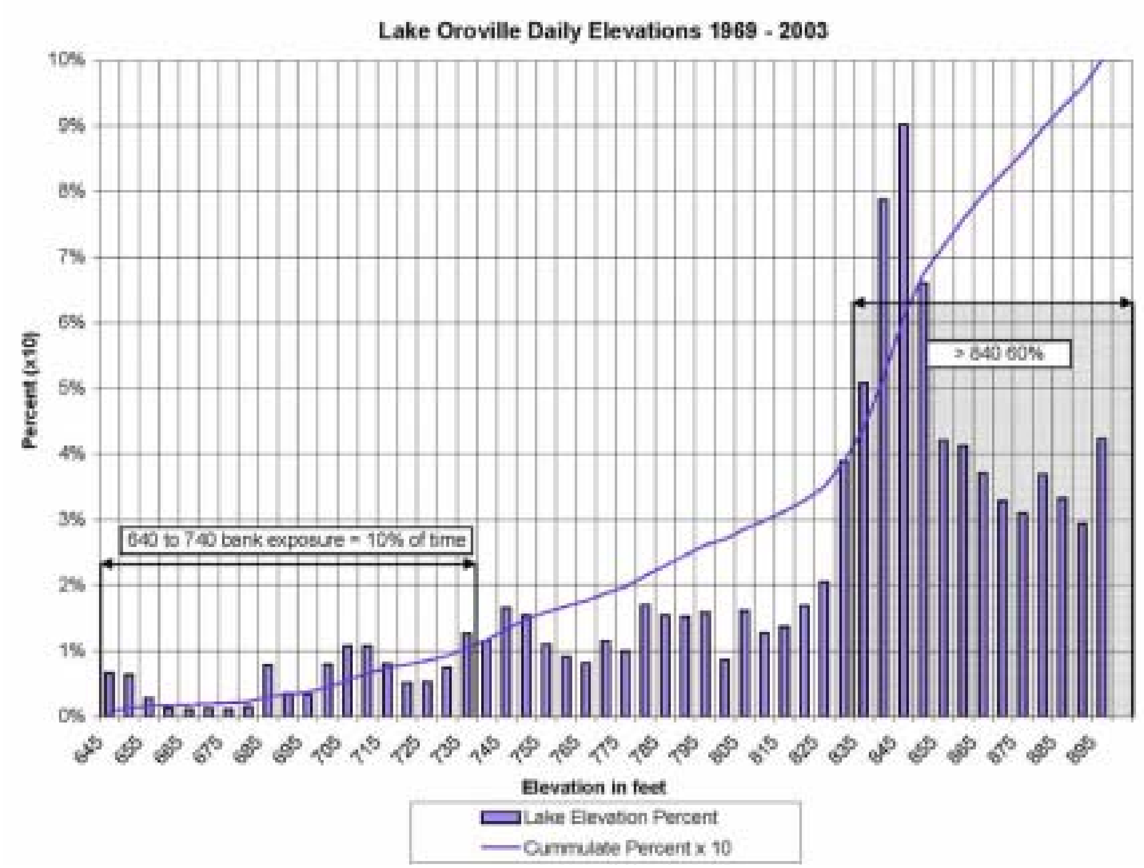


Figure 6.4-1. Lake Oroville Water Level Fluctuations – 1968 to 2003.

Determination of the total volume of sediment derived from eroded bank material is highly subjective. The method used for this report is to divide the total area of the Fluctuation Zone into sub-areas based on the Bank Erosion Level lengths compared to the total lake shore length. For example, if 30% of the shoreline was rated at Level 1 Bank Erosion (average 1.25 vertical feet of erosion), then 30% of area in the Fluctuation Zone was considered to have lost 1.25 vertical feet of soil.

Table 6.4-1 contains the total shoreline footage for the four Bank Erosion Levels for the separate branches of the lake and the main basin. Total volumes of sediment derived from the four Shoreline Bank Erosion Levels are also shown in Table 6.4-1. A total of about 15,200 acre-feet of sediment is estimated to be derived from shoreline erosion. This estimate assumes that the vertical depth of erosion observed at the shoreline continues down-slope at the same observed depth to the bottom of the Fluctuation Zone.

An alternative method of estimating the total volumes of sediment is to assume that erosion depth uniformly decreases to "0" (rather than remaining the same) to the bottom of the Fluctuation Zone. In this method, the total volume of shoreline erosion would be reduced by half to 7,600 acre-feet.

Bank Erosion Levels Total Volumes of Eroded Material

Lake Portion Name	Level 0 (0 - 0.5')				Level 1 (0.5 - 2.0')				Level 2 (2.0 - 5.0')				Level 3 (5.0 or more)				Total	
	Shoreline Length		Eroded Volume		Shoreline Length		Eroded Volume		Shoreline Length		Eroded Volume		Shoreline Length		Eroded Volume		Footage	Acre-Feet
	Feet	%	Acre-feet	%	Feet	%	Acre-feet	%	Feet	%	Acre-feet	%	Feet	%	Acre-feet	%		
Main Basin	16115	8.8%	39	1.6%	151307	82.2%	1844	74.7%	16057	8.7%	549	22.2%	662	0.4%	39	1.6%	184141	2470
Lower North Fork	23	0.0%	0	0.0%	90332	81.5%	1101	60.5%	19513	17.6%	666	36.6%	927	0.8%	54	3.0%	110796	1821
Upper North Fork	14484	9.0%	35	1.6%	134510	83.6%	1639	74.4%	6760	4.2%	231	10.5%	5080	3.2%	297	13.5%	160834	2202
West Branch	40178	21.9%	96	4.3%	128310	69.9%	1564	69.0%	11427	6.2%	390	17.2%	3653	2.0%	214	9.4%	183567	2265
Middle Fork	25960	13.2%	63	1.6%	109846	56.0%	1339	32.9%	35993	18.3%	1229	30.2%	24574	12.5%	1437	35.3%	196373	4067
South Fork	1247	0.9%	3	0.1%	119956	83.0%	1462	62.1%	19605	13.6%	669	28.4%	3786	2.6%	221	9.4%	144593	2355
Entire Lakeshore	98007	10.0%	236	1.6%	734080	74.9%	8848	58.9%	109354	11.2%	3731	24.6%	38682	3.9%	2263	14.9%	980304	**15181**

Note:
Computation of eroded volumes based on the following averages for each Erosion Level

Level 0	0.25 feet
Level 1	1.25 feet
Level 2	3.5 feet
Level 3	6 feet

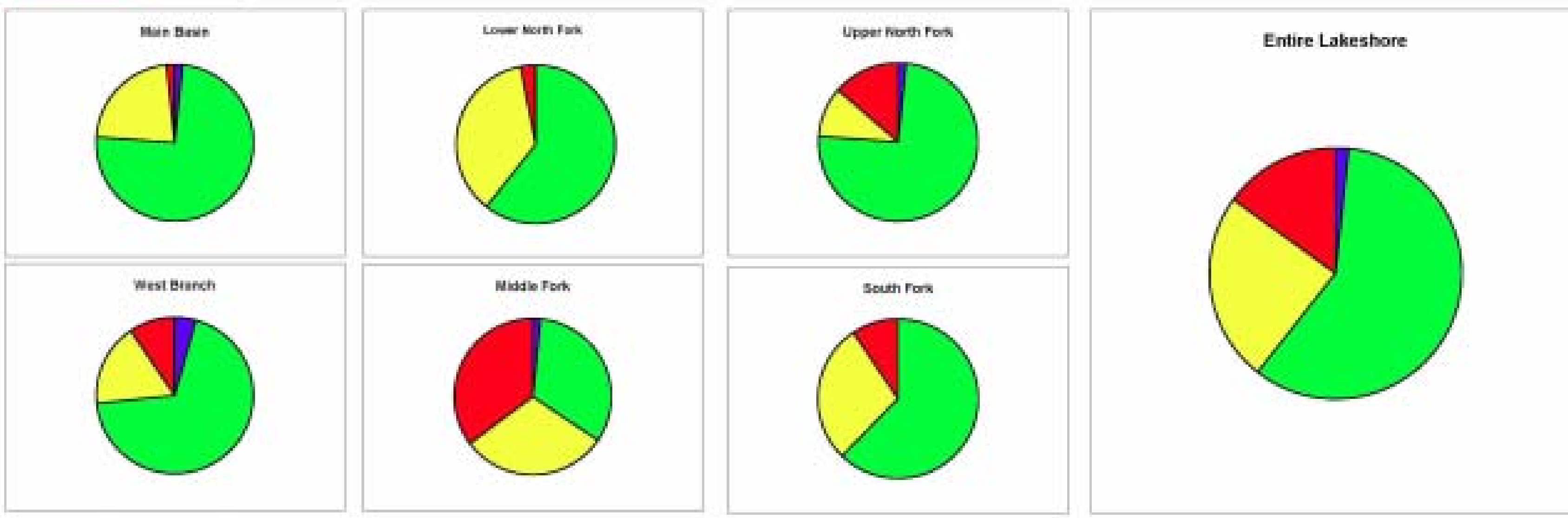


Table 6.4-1. **Bank Erosion Levels and Total Volumes of Eroded Material.**

6.5 SEDIMENT SAMPLING

6.5.1 Methodology

Grab samples from the sediment wedges on the North, Middle, and South Fork were collected in late fall, 2002 when the lake level had dropped to approximately 700 feet and the upper portions of sediment wedges were exposed. The North Fork sediment wedge was sampled near the confluence of Berry Creek and the North Fork (BS-NF-1). The Middle Fork sediment wedge was sampled approximately 500 feet upstream of Cross-Section MF-6 (BS-MF-1). The South Fork sediment wedge was sampled about 100 feet downstream of the Enterprise Bridge (BS-SF-1). The West Branch sediment sample wedge was not sampled. The sampling procedure consisted of collecting several shovelfuls of surface material at two to three locations near the downstream end of the upper portion of each sediment wedge and amalgamating the material in one bulk sample for each sediment wedge.

Sediment core samples from cross-section locations below the Fluctuation Zone were collected in summer, 2003. The sampling procedure consisted of dropping a gravity corer with 18” or 24” sample tubes from a boat, allowing the corer to free fall to the lake bottom, and then retrieving it by the attached rope. Core recovery was less than 50 percent; two attempts were made at each sampled cross-section location. Core samples were retrieved from cross-sections WB-2, NF-4, NF-6, MF-1, and MF-4. The clear plastic core tubes were removed from the gravity corer, capped, and taken to the DWR Red Bluff office. The tubes were kept in an upright position and minimally disturbed to preserve any internal structural characteristics. Water above the core sample was allowed to settle for several days then drained off.

The core samples were extruded from the core tube into another core tube that had previously been sliced in half. They were then sliced in half by pulling a thin-filament fishing line through the core. The two halves were pulled apart, laid side-by-side and allowed to thoroughly air-dry. Portions of the air-dried core samples (approximately 500 milligrams) were sent to the DWR Soils and Concrete Lab for grain-size analysis including hydrometer analysis for the finer-grained fraction.

6.5.2 Study Results

All three grab samples from the sediment wedges were composed of sands to fine gravels with less than 2% of the sample passing a #200 sieve (i.e., particle size smaller than very fine sand [0.062 mm]), (see Table 6.5-1 and Figure 6.5-1). Median size (D_{50}) for all three samples is in the medium sand range; D_{50} ranges from 0.5 mm for the North Fork to 0.96 mm for the South Fork.

Table 6.5-1. Sediment Wedge Grain Size Distribution

	Weight Percent												
Sample Number	**Sieve Size**	>3/4"	1/2-3/4"	.317-1/2"	#4-.317"	# 8 - # 4	# 16 - # 8	# 30 - # 16	# 50 - # 30	# 100 - # 50	# 200 - # 100	< # 200	Total
BS--SF-1	[redacted]	0%	1%	1%	5%	12%	23%	26%	21%	9%	0%	2%	100%
BS--NF-1	[redacted]	2%	0%	1%	3%	4%	8%	23%	38%	17%	1%	2%	100%
BS--MF-1	[redacted]	0%	1%	1%	3%	7%	15%	30%	33%	9%	0%	1%	100%

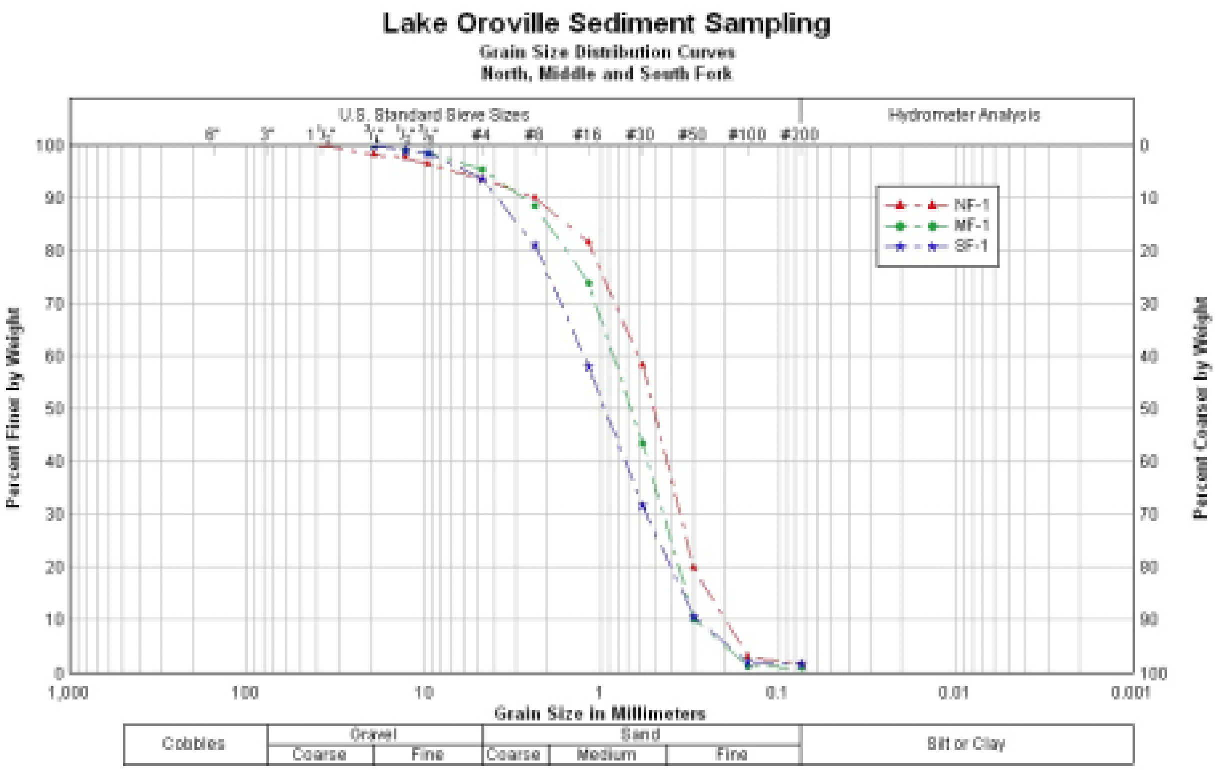


Figure 6.5-1. Sediment Wedge Grain Size Cumulative Distribution

All five core samples from cross-section locations below the Fluctuation Zone were composed of silts or clays with from 0% to 19% passing a #200 sieve (see Figure 6.5-2). Median size (D_{50}) for the five samples ranges from 0.012mm to 0.036mm.

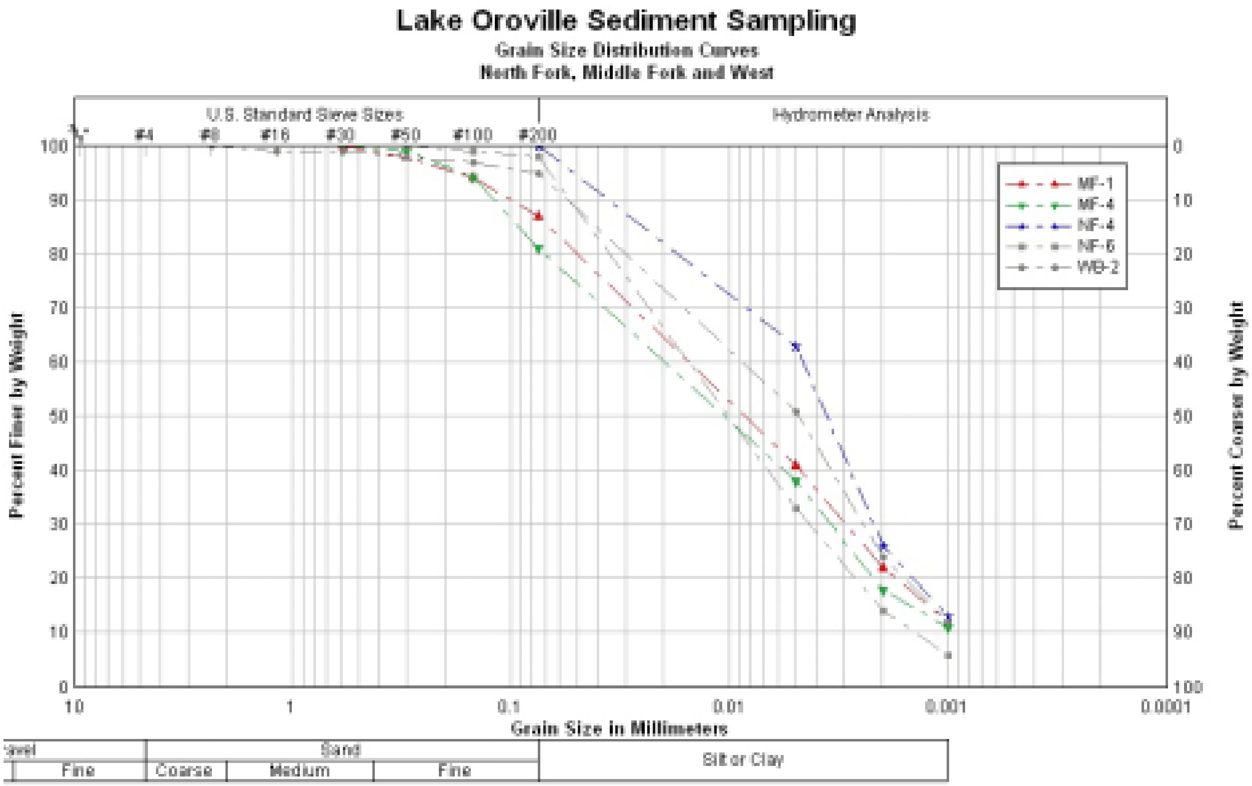


Figure 6.5-2. Core Samples Grain Size Cumulative Distribution

6.5.3 Analysis

The smaller median grain size for the North Fork sediment wedge sample BS-NF-1 is probably a result of coarser-grained sediments being trapped behind Big Bend Dam, and the aphanitic texture of the meta-volcanic and meta-sedimentary rocks in the area. The larger median grain size for the Middle Fork and South Fork samples is probably a result of the macrocrystalline texture of the igneous intrusive rocks upstream of the sample area.

Turbid density currents during times of high sediment influx are recognized as an important process for sediment accumulation in deeper parts of reservoirs (Morris and Fan, 1997). The fine-grained nature of the core samples is probably due to the rapid settling of coarser-grained sediments on or near the sediment wedges. As the in-lake water velocity slows closer to the dam, increasingly finer-grained sediments continue to drop out of the water column. This trend of “finer toward dam, coarser toward lake head” is well represented in the grain-size distribution of core samples taken at Cross-section NF-4 (CS—NF-4) and Cross-section NF-6 (CS—NF-6). NF-4 is approximately 8.3 miles upstream of the dam along the former river channel; NF-6 is approximately 11.2 upstream of the dam and approximately 0.8 miles downstream from the end of the sediment wedge. CS—NF-4 has a higher "percent finer" value for all sizes (i.e., sample is overall finer-grained). This trend is also evident when comparing "percent finer" values between samples CS—MF-1 and CS—MF-4, but to a lesser extent.

It was hoped that internal structural features of the core samples such as grain-size or color changes would provide some indication yearly sedimentation rates or significant deposition events. Any internal layering or color changes could not be discerned.

The color of the core samples ranged from burnt reddish-brown to light brown after air-drying. Core sample CS—MF-1 had a general orangish-brown color. The color is probably indicative of a large proportion of the sample being derived from eroded soils from shoreline erosion rather than being derived from upstream sediments migrating along the thalweg. Core sample CS—NF-4 and CS—WB-2 also display an orangish coloring indicative of soil origin. The remaining two core samples (CS—NF-6 and CS—MF-4) had a lighter brown to grayish-brown color. These two samples are from further upstream and probably contain a higher proportion of upstream migrating sediments.

6.6 DETERMINATION OF SEDIMENT IN STORAGE

6.6.1 Methodology

A common method of determining total sediment volume in a reservoir is the average end-area (Morris and Fan, 1997):

$$\text{Volume} = \frac{L(E_1 + E_2)}{2}$$

where L = length between ranges (i.e., cross-sections) and E_1 and E_2 are the cross-sectional end areas of the regions bounding the downstream and upstream limits of the reach between cross-sections. The 1993/94 Cross-section study utilized the average end-area method and determined that about 18,000 acre-feet of sediment had accumulated in Lake Oroville. The study also estimated that about 6,500 acre-feet of the total sediment was derived from bank erosion.

The total sediment volume in the reservoir is derived from incoming watershed erosion, and to shoreline bank erosion. Landslide activity is presumed to contribute a very small portion of the total. Because bank erosion and landslide activity are closely related, the sediment volumes determined from bank erosion are assumed to include a portion derived from landslide activity.

The thalweg bathymetry performed during this investigation provided longitudinal information of sedimentation along the tributaries. As a result, an increased understanding of the sediment wedge morphology, (such as beginning and ending locations, and slope break locations) provided additional range data for calculating total sediment. (Refer to Plates 6.2-2, 4, 6 and 7 for slope break locations.) Cross-sectional areas of the sediment wedges at their slope breaks were estimated by measuring the depth of sediment (i.e., elevation from 2002 bathymetry survey minus elevation from 1967 original thalweg profile data) and the channel width of sediment based on the 1967 original contour data; the area was then derived by calculating a simple triangular area:

$$Area_{SlopeBreak} = \frac{Width_{SlopeBreak} \ x \ Depth_{Sediment}}{2}$$

6.6.2 Study Results

Tables 6.6-1 through 6.6-4 show the total volumes of sediment for the four main tributaries; sediment wedge material is identified by the shaded portion of the tables. Sediment volumes are presented for each length of tributary between ranges. Table 6.6-5 compares the amount of sediment in each tributary that is derived from sediment wedge material versus non-sediment wedge. Based on calculations using the average end-area method, Lake Oroville has about 28,300 acre-feet of total sedimentation.

The South Fork sediment volumes contain the lowest proportion of wedge material (23%). Ponderosa Dam is located immediately upstream of Lake Oroville on the South Fork. Visual inspection of the reservoir behind Ponderosa Dam indicates that the reservoir has a large deposit of sediment; downstream transport of sediment into Lake Oroville is very minor. This assessment is substantiated by the habitat typing tasks which showed a gravel depletion in the South Fork upstream of Sucker Run Creek.

The Middle Fork sediment volumes contain the highest proportion of wedge material (53%). There are no major reservoirs in the Middle Fork watershed upstream of Lake Oroville. (Frenchman Lake and Lake Davis are located in the higher regions of the Middle Fork watershed, but have a relatively small catchment area.) As a result, sediment influx into Lake Oroville is essentially unimpeded.

The North Fork sediment volumes contain a moderate proportion of wedge material (41%). The North Fork watershed is the largest of the four main watersheds, but hydroelectric facilities upstream of Lake Oroville trap a large amount of the watershed sediment. However, large storm events are able to overwhelm the trapping efficiency of the upstream reservoirs (Photo 6.2-13) and substantial amounts of sediment can enter the Lake Oroville. Operating characteristics of several P.G. & E. reservoirs in the North

Fork canyon above Lake Oroville permit some passing of the sediment retained in those reservoirs.

The West Branch sediment volumes contain a moderate proportion of wedge material (39%). The West Branch watershed is the smallest of the four main watersheds. Some upstream sediment trapping occurs at Miocene Dam, but the habitat typing tasks did not indicate a substantial reduction in sediment downstream of Miocene Dam.

Table 6.6-1. West Branch Sediment Volumes

Range Name	Length From Start (ft.)	Interval Length (ft.)	Thalweg Deposition (sq.ft.)	Volume in cubic feet	Acre Feet
Lake End	50,330		0		
		9,225		0	0
WB-5	41,105		0		
		1,850		0	0
Wedge End	39,255		0		
		3,625		4,531,250	104
WB-4	35,630		2,500		
		1,750		7,739,375	178
Slope Break "A"	33,880		6,345		
		1,610		6,685,525	153
Slope Break "B"	32,270		1,960		
		2,165		6,170,250	142
Slope Break C"	30,105		3,740		
		725		1,754,500	40
Slope Break "D"	29,380		1,100		
		4,650		5,347,500	123
WB-3	24,730		1,200		
		1,275		822,375	19
Wedge Start **	23,455		90		
		5,770		11,511,150	264
WB-2	17,685		3,900		
		15,015		36,786,750	845
WB-1	2,670		1,000		
		2,670		2,670,000	61
Tributary Start *	0		1,000		
Totals				84,018,675	1,929

NOTES

* Tributary start is confluence of West Branch with North Fork.

** Shaded area identifies sediment wedge volume calculations.

Table 6.6-2. North Fork Sediment Volumes

Range Name	Length From Start (ft.)	Interval Length (ft.)	Thalweg Deposition (sq.ft.)	Volume in cubic feet	Acre Feet
Lake End	0		0		
		16,030		7,213,500	166
NF - 9	6,615		900		
		12,060		12,210,750	280
Wedge End	18,675		1,125		
		260		991,250	23
NF-8	18,935		6,500		
		9,290		154,678,500	3,551
NF-7	28,225		26,800		
		1,660		44,156,000	1,014
Slope Break "A"	29,885		26,400		
		3,325		55,993,000	1,285
Slope Break "B"	33,210		7,280		
		5,575		24,139,750	554
Wedge Start **	38,785		1,380		
		4,310		40,255,400	924
NF-6	43,095		17,300		
		6,580		82,250,000	1,888
NF-5	49,675		7,700		
		8,640		40,608,000	932
NF-4	58,315		1,700		
		9,290		46,914,500	1,077
NF-3	67,605		8,400		
		10,120		98,164,000	2,254
NF-2	77,725		11,000		
		16,090		110,216,500	2,530
FR-1	93,815		2,700		
		6,615		17,860,500	410
Tributary Start *	100,430		2,700		
Totals				735,651,650	16,888

NOTES

* Tributary start is 1950 feet upstream from centerline of dam.

** Shaded area identifies sediment wedge volume calculations.

Table 6.6-3. Middle Fork Sediment Volumes

Range Name	Length From Start (ft.)	Interval Length (ft.)	Thalweg Deposition (sq.ft.)	Volume in cubic feet	Acre Feet
Lake End	81,800		0		
		5,400		0	0
MF-8	76,400		0		
		5,110		0	0
MF-7	71,290		0		
		1,090		0	0
End of Wedge	70,200		0		
		8,150		49,042,625	1,126
Slope Break "A"	62,050		12,035		
		500		6,658,750	153
Slope Break "B"	61,550		14,600		
		2,780		46,287,000	1,063
MF-6	58,770		18,700		
		3,570		57,120,000	1,311
Slope Break "C"	55,200		13,300		
		200		2,111,000	48
Slope Break "D"	55,000		7,810		
		4,300		21,908,500	503
Slope Break "E"	50,700		2,380		
		1,525		5,059,188	116
Slope Break "F"	49,175		4,255		
		1,800		5,179,500	119
Wedge Start **	47,375		1,500		
		3,945		11,046,000	254
MF-5	43,430		4,100		
		12,160		48,032,000	1,103
MF-4	31,270		3,800		
		3,790		13,833,500	318
MF-3	27,480		3,500		
		4,650		16,507,500	379
MF-2	22,830		3,600		
		9,090		33,633,000	772
MF-1	13,740		3,800		
		13,430		45,662,000	1,048
FR-1	310		3,000		
		310		930,000	21
Tributary Start *	0		3,000		
Totals				363,010,563	8,334

NOTES

* Tributary start is confluence of Middle Fork with North Fork.

** Shaded area identifies sediment wedge volume calculations.

Table 6.6-4. South Fork Sediment Volumes

Range Name	Length From Start (ft.)	Interval Length (ft.)	Thalweg Deposition (sq.ft.)	Volume in cubic feet	Acre Feet
Lake End	46,100		0		
		11,160		0	0
Wedge End	34,940		0		
		4,330		4,600,625	106
Slope Break "A"	30,610		2,125		
		560		1,804,600	41
Slope Break "B"	30,050		4,320		
		1,010		3,812,750	88
Slope Break "C"	29,040		3,230		
		170		412,250	9
Slope Break "D"	28,870		1,620		
		890		961,200	22
Wedge Start **	27,980		540		
		13,690		18,755,300	431
SF-2	14,290		2,200		
		7,180		12,206,000	280
SF-1	7,110		1,200		
		7,110		8,532,000	196
Tributary Start *	0		1,200		
Totals				51,084,725	1,173

* Tributary start is confluence of South Fork with North Fork.
** Shaded area identifies sediment wedge volume calculations.

Table 6.6-5. Lake Oroville – Total Sediment Volumes

Tributary	Sediment Wedge (acre-feet)	Percent Wedge	Non-Sediment Wedge (acre-feet)	Percent Non-Wedge	Total Sediment (acre-feet)
West Branch	759	39%	1,170	61%	1,929
North Fork*	6,873	41%	10,015	59%	16,888
Middle Fork	4,439	53%	3,894	47%	8,334
South Fork	266	23%	907	77%	1,173
Totals	12,337	44%	15,987	56%	**28,323**

NOTES
* North Fork sediment wedge volume includes sediment upstream of wedge within fluctuation zone.

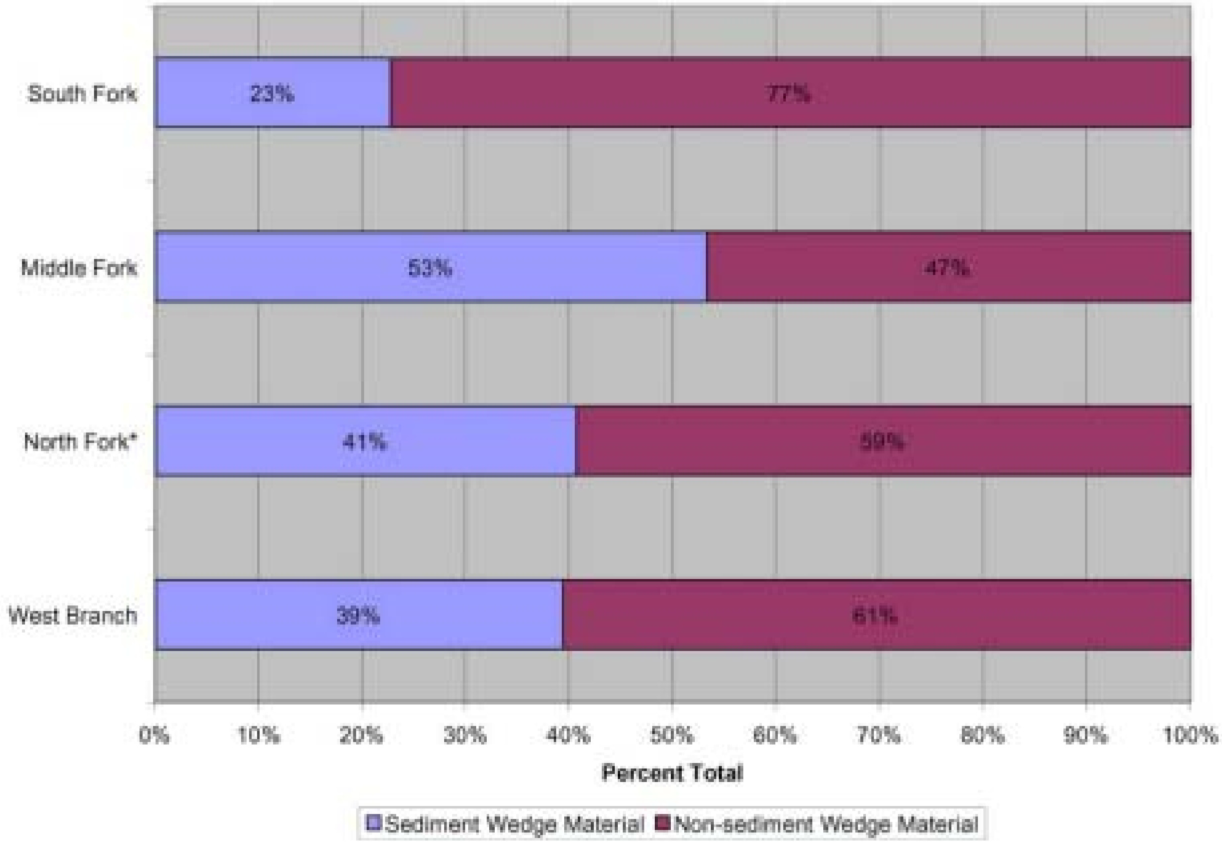


Figure 6.6-1. Sediment Wedge Volume vs. Non-Sediment Wedge Volume

The non-sediment wedge total volume for Lake Oroville is about 16,000 acre-feet (Table 6.6-5). This volume is assumed to be derived from shoreline bank erosion. The total volume of sediment derived from shoreline bank erosion was estimated to range from 7, 600 to 15,200 acre-feet (Table 6.4-1). Based on the non-sediment wedge total volume derived by the average end-area (16,000 acre-feet), it is reasonable to assume that the volume derived from shoreline bank erosion is closer to the higher end of the range (15,200 acre-feet) than the lower end.

A common procedure is to estimate the reservoir lifetime based on incoming sediment yield and reservoir capacity. The incoming sediment yield volume is the volume of sediment contained in the sediment wedges and the volume of very fine-grained material downstream from the sediment wedges that has settled out from the overlying water column. The volume of sediment derived from shoreline bank erosion is not included in the calculation of project lifetime; shoreline bank erosion volumes are essentially a mass transfer of material from higher up in the reservoir storage area to lower portions. The shoreline bank erosion estimation ranged from 7,600 acre-feet to 15,200. For the purposes of this calculation, it is reasonable to use an average of the low and high number: 11,400 acre-feet.

The storage capacity of Lake Oroville is approximately 3,500,000 acre-feet. Sediment yield since the initial filling of the reservoir in 1967 is about 16,900 acre-foot (i.e., 470 acre-feet per year). Assuming that incoming sediment yield rates remain constant, the reservoir lifetime is about 7,445 years (Table 6.6-6).

Table 6.6-6. Estimate of Years Until Complete Filling of Lake Oroville

Total Sediment	28,323	acre-feet
Shoreline Bank Erosion	(11,400)	acre-feet
Incoming Sediment	16,923	acre-feet
Average Annual Sediment Yield	470	acre-feet
Reservoir Capacity	3,500,000	acre-feet
Years to Totally Fill Reservoir Capacity	7,445	years

NOTES

Average Annual Sediment Yield based on 36 years since initial filling of reservoir.

7.0 CONCLUSIONS

The two primary tasks of SP-G1 are to assess channel resources (both above Lake Oroville and within the Fluctuation Zone) and determine the total sediment in storage by re-surveying the existing reservoir cross-sections and accessing other geomorphological conditions around the reservoir such as slope stability and bank erosion.

7.1 CHANNEL RESOURCES

Professional biological assessment of habitat is beyond the scope of this study plan. However, based on the geomorphological assessment and habitat typing of the West Branch and the Middle Fork tributaries above the full pool level (i.e., 900 feet) of Lake Oroville, impacts due to project operations were not observed. Fluctuating water levels discourage substantial delta and sediment deposits above the 900 foot level.

At the time of the field investigation for this study, upper portions of the fluctuation zone were exposed to fluvial (as opposed to lentic) conditions. Based on the geomorphological assessment and habitat typing of the four main tributaries within the fluctuation zone, the following preliminary conclusions are presented:

- The West Branch has in-stream gravel strata generally considered suitable for salmon spawning habitat in the upper portion of the Fluctuation Zone but silt accumulation on the downstream portions causes a degradation in spawning gravel quality
- Salmon spawning habitat in the North Fork is affected because of daily fluctuating flows from upstream hydroelectric facilities.
- The Middle Fork has abundant gravel sources from remnant sediment wedge lag deposits.
- The South Fork is gravel-starved above Sucker Run Creek and is subject to flow variations due to Ponderosa Dam. Spawning gravel quality improves downstream of Sucker Run Creek but gradually becomes sandier from remnant sediment wedge deposits.

Future flooding events (similar to 1997) will cause temporary episodic impacts to salmonid habitat in the upper portions of the Fluctuation Zone (from 800 ft to 900 ft) if floods occur at full pool level.

7.2 DETERMINATION OF SEDIMENT IN STORAGE.

The cross-section and thalweg bathymetry surveys revealed that substantial amounts of sediment occur in the middle upper arms of the lake ranging from about 720 feet in elevation to about 550 feet. Minor amounts of sediment were identified above the 720 foot level at the time of this investigation. Sediment accumulation rates in the cross section thalwegs downstream from the sediment wedges range from about 0.5 feet to 2.25 feet per year, averaging about 1.25 feet per year. It is uncertain if this sedimentation rate will continue; however, the rate is likely to decrease as sedimentation continues and the thalweg width increases.

Based on calculations derived from the cross-section and bathymetry surveys, the total volume of sediment in storage is about 28,300 acre-feet. Of this amount, about 11,400 acre-feet was estimated to be derived from shoreline bank erosion, and the remaining 16,900 acre-feet was identified as incoming sediment from the upstream watersheds. Based on a 36 year time period since the initial filling of Lake Oroville, annual sediment yield is about 470 acre-feet. If this rate of sediment field were to remain constant, sediment would completely fill the reservoir in about 7,400 years.

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